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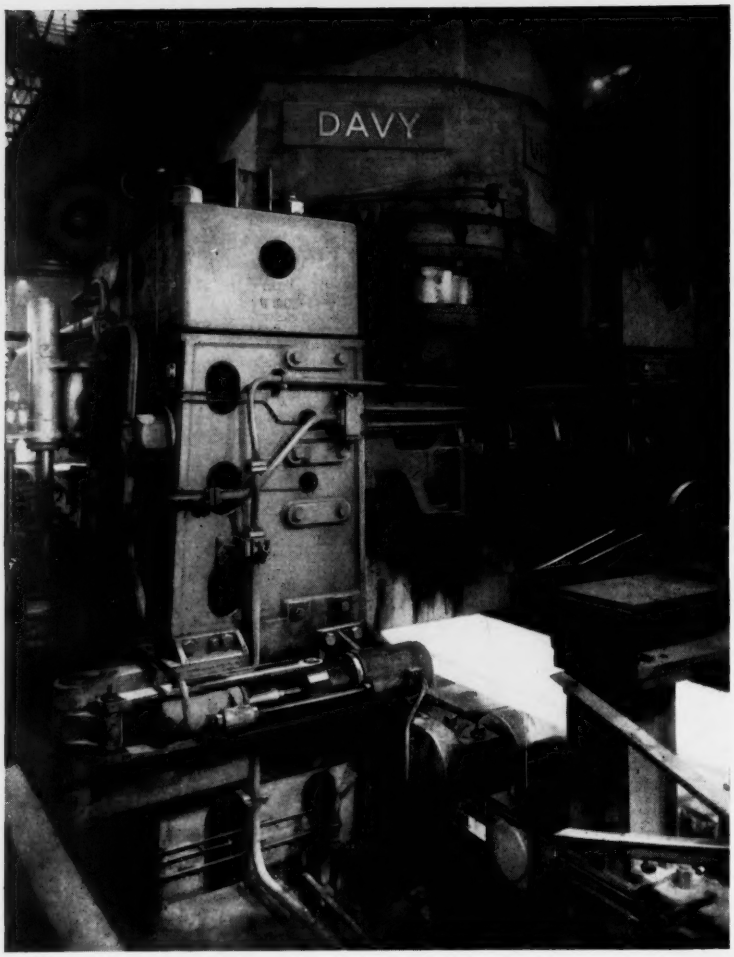


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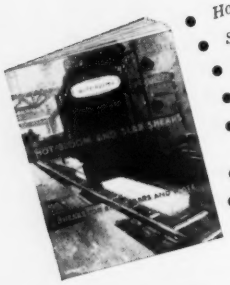

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THE Council has sent the following loyal address of congratulation to Her Majesty the Queen on the occasion of her Coronation:

*To Her Most Excellent Majesty*
*Queen Elizabeth II*

May it Please Your Majesty,

We present our humble duty to Your Majesty and on behalf of the Members of Council and Members of The Iron and Steel Institute tender our loyal and heartfelt congratulations on the occasion of Your Majesty's Coronation. It is our earnest prayer that Your Majesty's reign may be long, prosperous and peaceful.

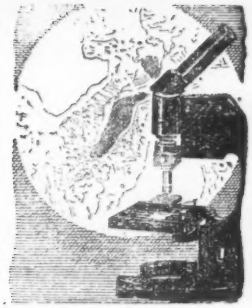
Your Majesty's decision graciously to confer Your Royal Patronage has given great pleasure to Members of The Iron and Steel Institute in all parts of the world. They are encouraged in their work by this evidence of the interest which Your Majesty takes in the well-being of the Iron and Steel Industry and the other industries associated with it and in the connected branches of science in which the Members are engaged.

On behalf of the Members of the Council and Members of the Institute we beg leave humbly to express to Your Majesty our loyalty and support in the onerous duties consequent on Your Majesty's accession to the Throne. We pray that Almighty God will long bestow on Your Majesty and on Your Majesty's illustrious husband, Prince Philip, Duke of Edinburgh, the blessings of health and happiness.

*President* — *President-Elect*

*Honorary Treasurer* — *Secretary*

*Dated 30th April, 1953*



# The 475° C. Hardening Characteristics of Some High-Alloy Steels and Chromium Irons

*By B. Cina, B.Sc., and J. D. Lavender*

SYNOPSIS

The phenomenon of '475° C. embrittlement' has been observed in certain duplex ($\gamma + \delta$) high-alloy steels after treatment in the range 350–525° C. Its development was investigated by measurement of hardness, electrical resistivity, and magnetic and mechanical properties, by microstructural changes, and by X-ray diffraction studies of filings, block samples, and electrolytically extracted residues. Comparative work was also carried out on two chromium irons. The effects occurred at a maximum after treatment at 475–500° C.; they increased with the percentage of δ-ferrite present in the duplex alloys and with the chromium content of the fully ferritic alloys. No stresses were found to accompany the ageing process, and, although a continuous alloy depletion of the ferritic matrix was suggested, no second phase was detected to account for the phenomenon. Despite the theoretical and actual formation of σ (after cold-working) at these low temperatures, an explanation of the phenomenon in terms of actual precipitation of σ seems to be improbable. 758

## Introduction

During recent investigations[1, 2] of sigma formation in duplex 18% chromium–8% nickel–3% molybdenum, titanium- or niobium-stabilized alloys between 500° and 950° C., it was noticed that, in the hardness/reheating-temperature curve, an unexpected increase in hardness occurred at the lower temperatures, which was tentatively attributed[1] to the precipitation of titanium carbide. More recent work by one of the authors[3] revealed what seemed to be a similar phenomenon in the duplex high-alloy valve steel *XCR*, containing about 24% Cr, 5% Ni, and 3% Mo, with no carbide-stabilizer. This indicated that, assuming the phenomenon to be the same in each alloy, the tentative explanation would not be suitable for *XCR*. This alloy showed that this secondary hardening occurred at a maximum at about 475–500° C. The phenomenon known as '475° C. embrittlement' has long been recognized in 20–70% chromium irons after they have been exposed for even fairly short periods at about 475° C.; it is generally accompanied by an increase in hardness and tensile strength and a decrease in ductility. Various explanations of the phenomenon have been given,[4–11] but no conclusive evidence has yet been brought forward to clarify the matter, although sigma has been considered[4, 6, 8, 9, 11] to be the most likely cause. The possibility that the mechanism of the hardening observed in all these duplex and fully ferritic alloys might be similar led to the present investigation, which was planned to determine in which of the more common types of Fe–Ni–Cr alloys this secondary-hardening phenomenon was encountered, and, if possible, its precise nature and cause.

### Steels Investigated and Preliminary Treatments

Ten alloys were selected for study; Table I gives the analyses and the structures of the casts in their respective softened conditions, *i.e.*, before exposure. Owing to shortage of material, some of the work reported was carried out on additional casts of compositions very similar to those of alloys 1, 2, 7, and 8. Their analyses and structures are also given in Table I, which shows that the whole series of casts includes five duplex ($\gamma + \delta$) alloys, three examples of fully austenitic material, and two of fully ferritic material.

All the alloys, with the exception of 6 and 10, were obtained from normal production casts, and were received in the form of hot-rolled bar, $\frac{1}{2}$–$1\frac{1}{8}$-in. dia. Alloys 6 and 10 were 30-lb. laboratory melts, the $2\frac{1}{4}$-in. square ingot being forged down to $\frac{1}{2}$-in. dia. bar.

Before any hardening treatment, all the casts except the 21% and 30% chromium alloys were given a softening treatment of 1 hr. at 1050° C., W.Q., which left the alloys in the metastable conditions listed in Table I. The 21% chromium cast was tested after two prior treatments, $\frac{1}{4}$ hr. at 1100° C., W.Q., and 2 hr. at 800° C., W.Q., which left the material in a hard and a soft condition respectively; they will be explained later. The 30% chromium material was given a prior softening treatment of 2 hr. at 800° C., W.Q. The samples were treated over the range 300–900° C. for 1 week, 1 month, or longer. The lower temperature limit was determined simply by the effective absence of hardening after a selected

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Mr. Cina and Mr. Lavender are at the Brown-Firth Research Laboratories, Sheffield.

**Table I**
**COMPOSITION AND STRUCTURE OF ALLOYS USED**

| Alloy No. | Nominal Composition | Cast No. | C, % | Si, % | Mn, % | S, % | P, % | Cr, % | Ni, % | Mo, % | Ti, % | $N_2$, % | Structure |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 21% Cr | 06031 | 0·03 | 0·25 | 0·74 | n.d. | n.d. | 20·52 | 0·16 | ... | ... | 0·019 | δ-ferrite + $(Cr,Fe)_{23}C_6$ |
| 2 | 30% Cr | XF40632 | 0·07 | 0·71 | 0·65 | n.d. | n.d. | 29·80 | 1·89 | ... | ... | 0·220 | δ-ferrite + $(Cr,Fe)_{23}C_6$ |
| 3 | 24/21 | HFD7982 | 0·14 | 1·30 | 0·60 | 0·019 | 0·016 | 25·00 | 20·90 | ... | ... | ... | $\gamma$ + $(Cr,Fe)_{23}C_6$ |
| 4 | 18/8 | N760 | 0·12 | 0·55 | 0·34 | 0·019 | 0·020 | 17·86 | 7·90 | 0·34 | ... | 0·029 | $\gamma$ + $(Cr,Fe)_{23}C_6$ |
| 5 | 18/8/Ti | HFD826 | 0·09 | 0·87 | 0·87 | 0·017 | 0·019 | 18·63 | 8·41 | ... | 0·60 | ... | $\gamma$ + δ (5–10%) + TiC |
| 6 | 18/10/Ti | G2407 | 0·15 | 1·12 | 0·51 | n.d. | n.d. | 17·94 | 10·18 | ... | 0·59 | ... | $\gamma$ + TiC |
| 7 | 18/8/Mo | Y | 0·07 | 0·28 | 0·36 | n.d. | n.d. | 18·13 | 8·26 | 2·67 | ... | ... | $\gamma$ + δ (5%) + $(Cr,Fe)_{23}C_6$ |
| 8 | 18/8/Mo/Ti | X | 0·07 | 0·22 | 0·41 | n.d. | n.d. | 18·12 | 8·48 | 3·24 | 0·35 | ... | $\gamma$ + δ (25%) + TiC |
| 9 | 24/5/Mo | 09755 | 0·50 | 0·86 | 0·86 | 0·005 | 0·025 | 23·66 | 4·91 | 2·67 | ... | ... | $\gamma$ + δ (45%) + $(Cr,Fe)_{23}C_6$ |
| 10 | 24/5/Mo/ low C | G2532 | 0·06 | 0·58 | 0·33 | n.d. | n.d. | 24·83 | 5·53 | 2·85 | ... | ... | $\gamma$ + δ (65%) + $(Cr,Fe)_{23}C_6$ |
| 1*A* | 21% Cr | 06030 | 0·03 | 0·28 | 0·70 | n.d. | n.d. | 20·60 | 0·20 | ... | ... | 0·021 | δ-ferrite + $(Cr,Fe)_{23}C_6$ |
| 2*A* | 30% Cr | Z | 0·09 | 0·96 | 0·71 | n.d. | n.d. | 30·04 | 1·85 | ... | ... | 0·24 | δ-ferrite + $(Cr,Fe)_{23}C_6$ |
| 7*A* | 18/8/Mo | 35645 | 0·07 | 0·56 | 0·35 | 0·006 | 0·017 | 18·44 | 8·75 | 2·76 | ... | ... | $\gamma$ + δ (10%) + $(Cr,Fe)_{23}C_6$ |
| 8*A* | 18/8/Mo/Ti | 09482 | 0·07 | 0·50 | 0·41 | 0·004 | 0·023 | 18·84 | 8·45 | 3·30 | 0·30 | ... | $\gamma$ + δ (20–25%) + TiC |

n.d. = Not determined (0·005–0·025% S, 0·015–0·025% P)

period of time (1 week). The range was extended to 900° C. to show whether some of the alloys could form sigma, and to compare the relative hardening or embrittling effect at 475° C. with that obtained at the upper optimum temperature for sigma formation.

In most cases, separate samples about $\frac{1}{2}$ in. long sawn from the bars were used for investigating the effects of temperature or duration of exposure on the hardness and on the microstructure, and each sample was water-quenched from the treatment temperature.

## EXPERIMENTAL PROCEDURE

### Determination of Mechanical Properties

Hardness measurements were carried out with a Vickers Diamond Hardness Machine, using a 30-kg. load. Izod impact and tensile measurements were carried out for only some of the conditions of heat-treatment of the alloys. Samples for tensile or impact properties were heat-treated in the form of bar, and the test pieces were machined after treatment.

### Preparation of Samples for Micro-examination

After water-quenching from the treatment temperature, each sample for micro-examination was sectioned transversely to the direction of rolling, linished, and polished in the usual way to 000 emery. Final polishing was carried out electrolytically, using a 4 : 1 methyl alcohol : perchloric acid bath as electrolyte and a Staybrite steel sheet as cathode. Polishing was carried out for 30 sec. at room temperature; the bath was water-cooled through an immersed coil and was stirred mechanically during polishing. Such polishing had a slight etching effect on the sample, which facilitated later etching by other reagents.

### X-Ray Methods

An X-ray examination by the usual grazing-incidence method was carried out on several of the block specimens used for the microscopic work.

An investigation was also carried out on filings from alloys 24/5/Mo, 18/8/Mo/Ti, and 30% Cr. Filings were taken across transverse sections of softened bars and were aged *in vacuo*, starting from the two initial conditions:

(i) Filed and vacuum annealed
(ii) As filed (*i.e.*, heavily cold-worked).

A 19-cm. camera was used for the filings. Various X-radiations were used, depending upon the particular

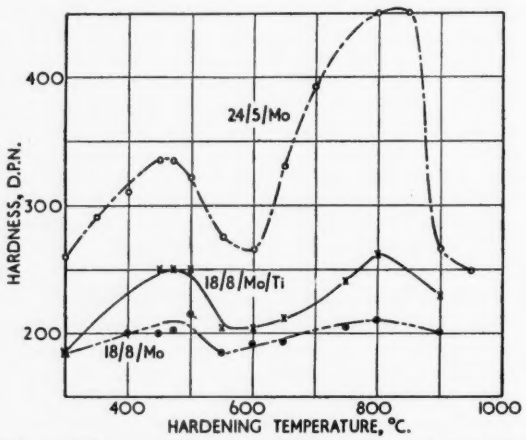



**Fig. 1—Effect on hardness of alloys 7, 8, and 9 of one week's exposure at various temperatures**

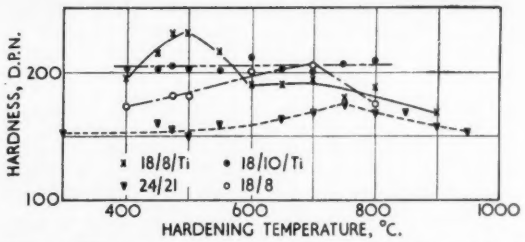



**Fig. 2—Effect on hardness of alloys 3, 4, 5, and 6 of one week's exposure at various temperatures**

information required. In one or two cases, monochromatic $MnK_\alpha$ radiation was used, with a single-crystal (NaCl) monochromator.

**Examination of Residues**

Chemical residues were extracted electrolytically[1] from bar samples of 24/5/Mo that had been treated for 1 month at 475° and 600° C. These samples were examined by the method described for the filings.

**Determination of Resistivity and Magnetic Properties**

Only the 30% Cr alloy 2*A* was used in these tests. Bars were machined to $\frac{3}{8}$ in. dia. × 8 in. long, and the measurements were carried out by standard methods.

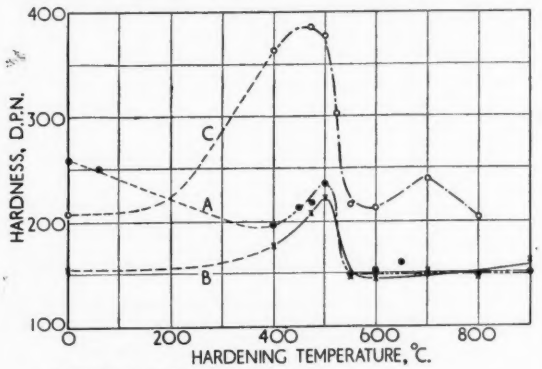
## DISCUSSION OF RESULTS

### HARDENING CHARACTERISTICS OF THE ALLOYS

**Effect of Temperature on Hardness Attained**

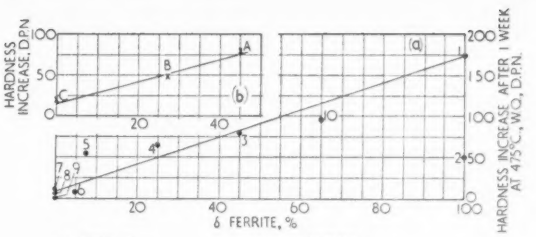
In the following section, primary hardness is taken to be that developed at 600–900° C. and secondary hardness that developed below 600° C.

Figures 1–3 show the relationship between hardness and temperature after 1 week's exposure for all the alloys examined. Some alloys have two hardness maxima, although the positions and relative intensities of these are not identical in each case. The maximum hardness at the higher temperature occurs at about 800° C. for the duplex alloys 7, 8, and 9, which is in keeping with their observed sigma-forming characteristics.[1, 3] The duplex and fully austenitic alloys 18/8/Ti and 18/10/Ti showed no primary hardness maximum. The presence of a primary hardness maximum in the fully austenitic 24/21 alloy is in accord with the formation of σ at those temperatures.[12] The primary hardness in the fully austenitic 18/8 alloy has been shown elsewhere[13] to be due to the precipitation of $(Cr,Fe)_{23}C_6$. In the fully ferritic alloys, the 21% Cr alloy 1 showed no primary hardness maximum, but this was observed in the 30% Cr alloy 2, in keeping with its known σ-forming properties.[6, 8, 14, 15] All these duplex and austenitic alloys, except the fully austenitic 18/8 and 18/10/Ti, showed a secondary hardness maximum between 400° and 500° C., although there was only a suggestion of secondary hardness in the 24/21 alloy after 1 month's exposure.




*A* 21% Cr iron: ½ hr. at 1100°C., W.Q.
*B* 21% Cr iron: ½ hr. at 1100°C., W.Q. + 2 hr. at 800°C., W.Q.
*C* 30% Cr iron

**Fig. 3—Effect on hardness of chromium irons of one week's exposure at various temperatures**




1. 30% Cr
2. 21% Cr
3. 24/5/Mo
4. 18/8/Mo/Ti
5. 18/8/Ti
6. 18/8/Mo
7. 18/8
8. 24/21
9. 18/10/Ti
10. 24/5/Mo/low C

24/5/Mo

*A* 1 hr., 1050° C., W.Q., + 1 week, 475° C., W.Q.
*B* 1 hr., 1050° C., W.Q., + 16 hr., 800° C., W.Q., + 1 week, 475° C., W.Q.
*C* 1 hr., 1050° C., W.Q., + 1 month, 800° C., W.Q., + 1 week, 475° C., W.Q.

**Fig. 4—Relationship between δ-ferrite and increase in hardness after 1 week at 475° C.**

Figure 3 shows the effect of prior treatment on the hardness/temperature relationship for the 21% Cr iron. Curve *A* was obtained after a prior treatment of ¼ hr. at 1100° C., W.Q., and curve *B* after ¼ hr. at 1100° C., W.Q. + 2 hr. at 800° C., W.Q. In the former condition the hardness is 258 D.P.N., and in the latter it is 160 D.P.N. Both curves show no maximum above 550° C., but there is a definite maximum at about 500° C., the values being slightly higher in the 1100° C., W.Q., prior-treated sample.

Curve *C* of Fig. 3 shows the very marked secondary and smaller primary hardening obtained in the 30% Cr alloy, the increase in secondary hardness being greater than that observed in any of the other alloys.

*Importance of Initial Structure*—Whilst Figs. 1–3 have shown that primary and secondary, or only secondary, hardening can be developed in duplex and fully ferritic alloys after one week at temperature, only primary hardening was detected in the fully austenitic alloys, although there was a suggestion that secondary hardening occurred in a fully austenitic 24% Cr, 21% Ni alloy. Further indication of the importance of the presence of ferrite for the development of secondary hardening is given by the fact that the greater secondary-hardness increase is associated with a higher initial δ-ferrite content in different alloys, and by an almost linear relationship between this hardness increase and δ-ferrite content (varied by different prior heat-treatments) in the same alloy. These relationships are shown in Figs. 4*a* and *b*, the latter being obtained for the 24/5/Mo

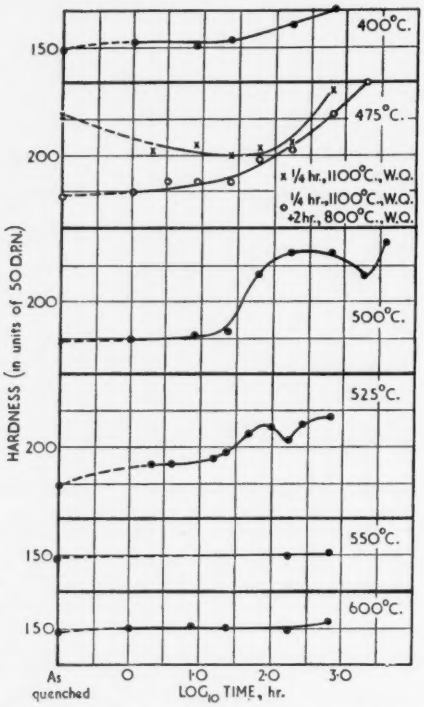



**Fig. 5—Effect of time at temperature on hardness attained by 21% Cr iron**

alloy. It would, therefore, seem that although the presence of ferrite may not be essential for secondary hardening, the hardness increase obtained is roughly proportional to the amount initially present.

The results of this section may be summarized as follows. The fully ferritic and duplex ($\gamma + \delta$) alloys all showed a 'secondary' maximum at about 450–500° C., and only one of the three fully austenitic casts showed even a suggestion of such a maximum in the lower temperature range. The maximum increase in secondary hardness was obtained in the fully ferritic alloy of highest chromium content (2). The secondary-hardness increase depended on

(i) The percentage of ferrite present before ageing
(ii) The chromium content of the ferrite.

### Effect of Exposure Time on Hardness Attained

The hardening characteristics of the five alloys 24/5/Mo, 18/8/Mo/Ti, 18/8/Mo, 21% Cr, and 30% Cr, at temperatures between 400° and 600° C., were determined, and some are shown in Figs. 5–8.

As insufficient material was available from the 18/8/Mo/Ti (cast *X*), 18/8/Mo (cast *Y*), and 21% Cr (cast 06031) bars, three further casts of alloys of very similar composition were used for determining the mode of hardening and the effect of exposure on impact and tensile properties. The compositions of these casts are given in Table I.

An examination of the hardness/log-time curves of the 21% Cr and 30% Cr alloys for ageing temperatures of 400–600° C. and 400–800° C. respectively (*see* Figs. 5 and 6) suggests that different modes of hardening are operative at 400–525° C. as compared with 550° C. and above. The outstanding features in these curves are:

(i) The presence of an incubation period before hardening at 400–525° C. in the 21% Cr alloy, and only at 400° C. in the 30% Cr alloy
(ii) The greater increase in hardness of the higher chromium alloy for the same ageing period at 400–500° C.
(iii) The intermediate softening observed in both alloys at 500° and 525° C.
(iv) The latter softening occurred earlier with higher ageing temperatures (for the same alloy) and higher chromium contents (for the same ageing temperature).

The hardening curves at 550–700° C. (for the 30% Cr alloy) are due to the visible precipitation of hard σ particles, the 21% Cr alloy showing negligible hardening at 550° and 600° C. Figure 5 shows the effect of prior treatment on the ageing characteristics of

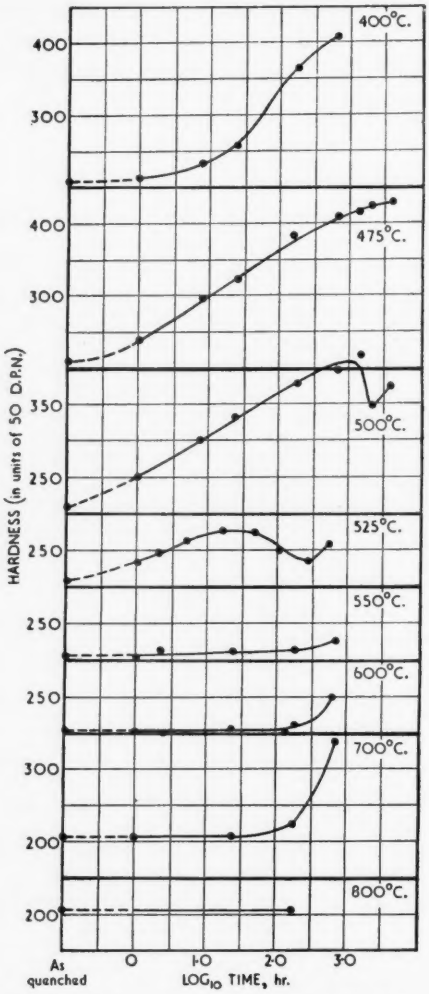



**Fig. 6—Effect of time at temperature on hardness attained by 30% Cr iron**

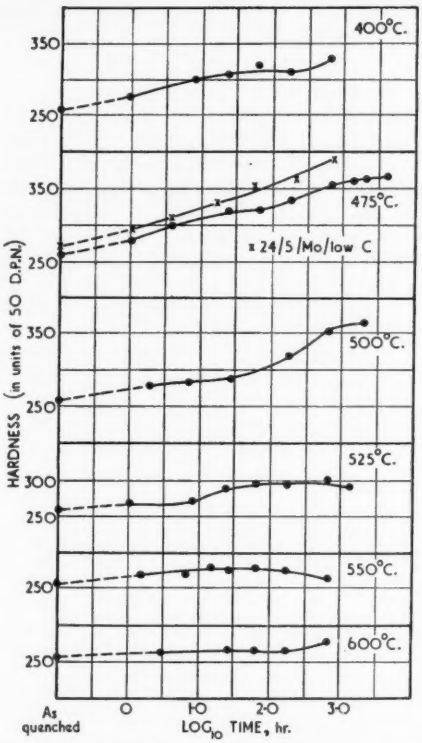



**Fig. 7—Effect of time at temperature on hardness attained by steel 24/5/Mo**

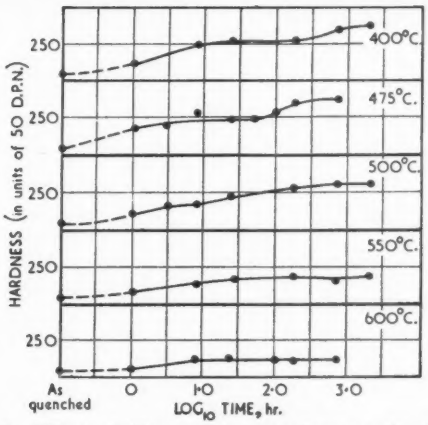



**Fig. 8—Effect of time at temperature on hardness attained by steel 18/8/Mo/Ti**

the 21% Cr iron at 475° C. After the initial softening at the ageing temperature of the sample prior-treated at 1100° C., W.Q., both curves showed similar characteristics, the 1100° C., W.Q., sample maintaining a higher hardness for the periods investigated.

The hardness/log-time curves for the 24/5/Mo and 18/8/Mo/Ti alloys for ageing temperatures of 400–600° C. are given in Figs. 7 and 8. The 18/8/Mo alloy showed hardening characteristics similar to, although less marked than, those of the 18/8/Mo/Ti alloy for the same ageing times and temperatures; *e.g.*, the increases in hardness after a month at 400°, 475°, and 550° C. were about 15, 32, and 7 D.P.N. respectively. Corresponding curves for the 24/5/Mo alloy for 650°, 700°, 750°, and 800° C. have already been published.[3] As with the fully ferritic 30% Cr alloy, the duplex alloys show hardening due to visible σ precipitation at the higher ageing temperatures (600–800° C.), and hardening characteristics similar to the 30% Cr alloy at the lower temperatures (400–550° C.). The outstanding features of the hardening curves of the duplex alloys are as follows:

(i) All three alloys showed an increase in hardness at 400°, 475°, and 500° C., there being a suggestion of an intermediate flattening in the curves
(ii) At 525° and/or 550° C., the hardness curves tended to flatten out
(iii) The extent of hardening was greater at any one temperature for the alloys in the order 24/5/Mo, 18/8/Mo/Ti, and 18/8/Mo.

Figure 7 shows the effect of different carbon contents in the 24/5/Mo type of alloy on the rate of hardening at 475° C. The lower-carbon cast maintains a consistently higher hardness for all periods up to 1 month at this temperature and shows a similar mode of hardening.

### Ageing of 30% Cr Iron

It is interesting to consider the effect of ageing the 30% Cr alloy at some temperature in the secondary hardening range, followed by ageing at a higher temperature. The results are given in Table II. The

**Table II**

**RESULTS OF AGEING 30% CHROMIUM STEEL**

| A | | B | | C | |
|---|---|---|---|---|---|
| Heat Treatment | Hardness, D.P.N. | Heat Treatment | Hardness, D.P.N. | Heat Treatment | Hardness, D.P.N. |
| 2 hr. at 800° C. | 208 | 2 hr. at 800° C. | 208 | 2 hr. at 800° C. | 208 |
| + 168 hr. at 500° C. | 339 | + 168 hr. at 400° C. | 380 | + 164 hr. at 400° C. | 380 |
| + 1 hr. at 700° C. | 201 | + ¼ hr. at 475° C. | 371 | + ¼ hr. at 518° C. | 341 |
| + 168 hr. at 500° C. | 343 | + 1¼ hr. at 475° C. | 353 | ... | ... |
| + 1 hr. at 700° C. | 202 | + 24 hr. at 475° C. | 346 | ... | ... |
| + 168 hr. at 500° C. | 360 | + 48 hr. at 475° C. | 379 | ... | ... |
| + 1 hr. at 700° C. | 203 | ... | ... | ... | ... |

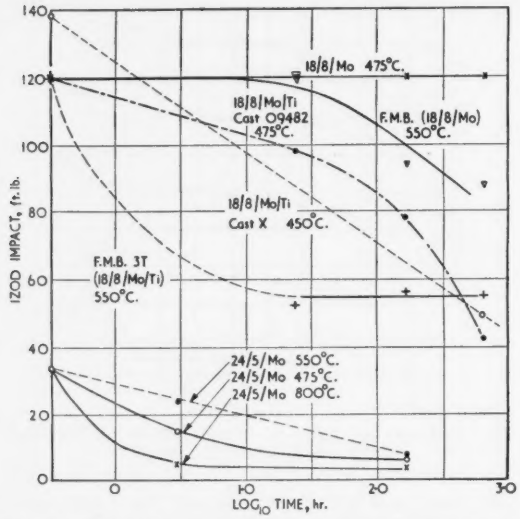



**Fig. 9—Effect of time at temperature on impact strength**

results reported under *A* are in keeping with the well-established commercial practice of removing 475° C. embrittlement. The results under *B* and *C* show that a sample hardened by ageing at 400° C. undergoes an initial softening when subsequently aged at some higher temperature (475° and 518° C.) in the secondary hardening range, and then recommences hardening (at 475° C.). This is a new feature of the phenomenon, and will be referred to later in the discussion. This behaviour is in some ways similar to the ageing of aluminium–copper, where the softening that occurs on ageing at a higher temperature, after prior hardening at a low temperature, has been called 'retrogression.'[16] When a sample of the 30% Cr alloy (prior-softened at 800° C.) was treated for 1 month at 700° C., about 30% of σ, as measured by point counting,[17] was detected in the microstructure. Subsequent exposure (1 week at 500° C.) of this sample in the secondary hardening range showed no significant increase in σ content, but resulted in the hardness increasing from 330 to 470 D.P.N. This increase of 140 D.P.N. is identical with that obtained in a sample aged for 1 week at 500° C. without any intermediate treatment at 700° C., and suggests that secondary hardening is not directly associated with σ formation.

### Effect of Exposure Time and Temperature on Impact Properties

In the fully ferritic alloys, impact properties were determined only on the 21% Cr iron, but since this material was highly brittle in both the hardened and softened conditions, no significant change in impact properties could be detected. This brittleness was probably due to the presence of a precipitate (carbide) at the grain boundaries. This precipitate was unaffected by ageing, so that the material would remain brittle throughout treatment.

No mechanical properties were determined for the 30% Cr alloy, although it is well established [6, 9] that such material shows a marked increase in hardness and tensile strength and a decrease in ductility and impact properties after '475° C.' treatment.

### Duplex Alloys

*24/5/Mo*—As would be expected, a decrease in Izod impact values was obtained with increasing time at the hardening temperatures. Figure 9 shows the decrease observed for 3 hr. and 1 week at 475°, 550°, and 800° C. Although the hardness of samples held at these temperatures is 334, 275, and 450 D.P.N. respectively after 1 week, all have embrittled to almost the same extent, and the sample held for 3 hr. at 475° C. is harder (300 D.P.N.), and yet less brittle, than one treated for 1 week at 550° C. (275 D.P.N.). Both these phenomena suggest that the brittleness observed is not solely a consequence of hardness increase.

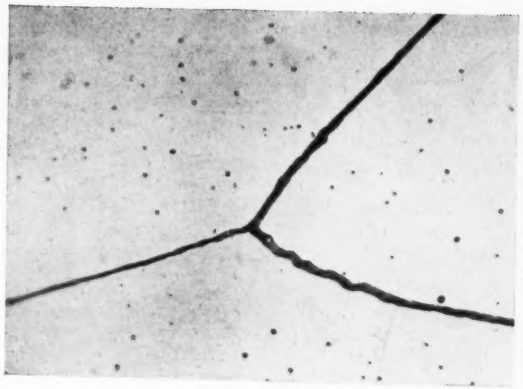
*18/8/Mo/Ti and 18/8/Mo*—Figure 9 shows the impact properties obtained after periods of up to 1 month at 475° and 550° C. Embrittlement occurs more rapidly at 550° than at 475° C. for both alloys, and to a greater extent in the Ti-stabilized material. There was a greater increase in hardness after 1 week at 475° than at 550° C. in both alloys, again suggesting that embrittlement was not entirely a consequence of hardness increase.

*Tensile Properties*—The investigation was restricted to the 18/8/Mo/Ti and 18/8/Mo alloys, and was confined to determining the effects obtained after up to

## Table III

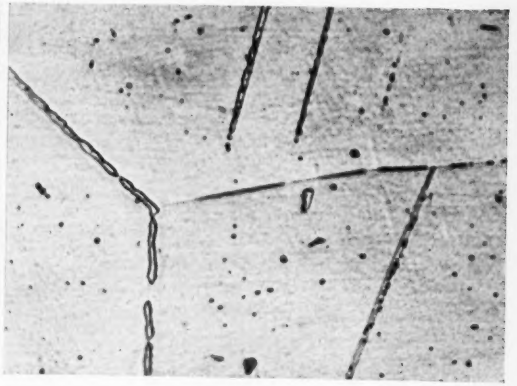
### EFFECT OF HEAT TREATMENT ON TENSILE PROPERTIES OF DUPLEX ALLOYS

| Heat Treatment | Steel 18/8/Mo/Ti (Cast 09482) | | | | | | | Steel 18/8/Mo (Cast 35645) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Limit of Proportionality | Proof Stress | | | Maximum Stress | Elongation, % | Reduction in Area, % | Limit of Proportionality | Proof Stress | | | Maximum Stress | Elongation, % | Reduction in Area, % |
| | | 0·05% | 0·10% | 0·50% | | | | | 0·05% | 0·10% | 0·50% | | | |
| | Tons/sq. in. | | | | | | | Tons/sq. in. | | | | | | |
| 1 hr. at 1050° C., W.Q. | 9·6 | 16·5 | 19·3 | 27·5 | 43·8 | 48·0 | 71·5 | 10·25 | 17·1 | 18·55 | 23·1 | 41·4 | 58·0 | 73·0 |
| 24 hr. at 475° C., W.Q. | 13·45 | 19·6 | 22·0 | 32·6 | 51·75 | 44·0 | 67·5 | 10·20 | 19·2 | 20·6 | 25·7 | 44·7 | 52·5 | 71·0 |
| 168 hr. at 475° C., W.Q. | 13·20 | 20·4 | 23·0 | 33·7 | 53·5 | 38·0 | 65·5 | 12·25 | 18·8 | 19·92 | 25·15 | 45·25 | 52·5 | 69·0 |
| 672 hr. at 475° C., W.Q. | 11·0 | 17·6 | 20·4 | 32·2 | 59·0 | 35·0 | 56·5 | 9·25 | 15·3 | 17·15 | 23·95 | 47·0 | 48·5 | 68·0 |
| 24 hr. at 550° C., W.Q. | 9·4 | 16·6 | 19·6 | 30·6 | 51·5 | 38·5 | 55·0 | 9·4 | 15·95 | 17·65 | 21·35 | 45·25 | 51·0 | 65·0 |
| 168 hr. at 550° C., W.Q. | 9·7 | 18·0 | 21·0 | 29·7 | 49·1 | 41·0 | 56·5 | 9·55 | 14·45 | 16·22 | 22·15 | 43·1 | 50·0 | 62·0 |
| 672 hr. at 550° C., W.Q. | 12·0 | 19·5 | 22·3 | 30·0 | 49·8 | 37·5 | 55·0 | 7·7 | 14·68 | 16·65 | 22·65 | 44·9 | 50·0 | 60·5 |

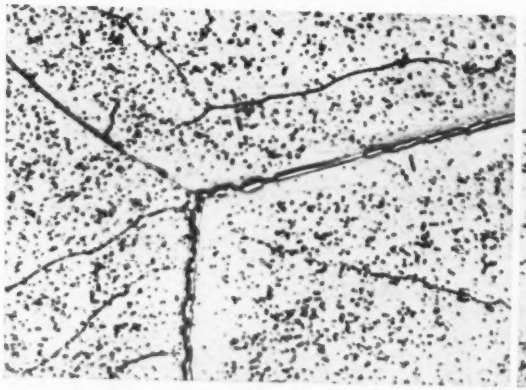


(*a*) 1100° C., W.Q.

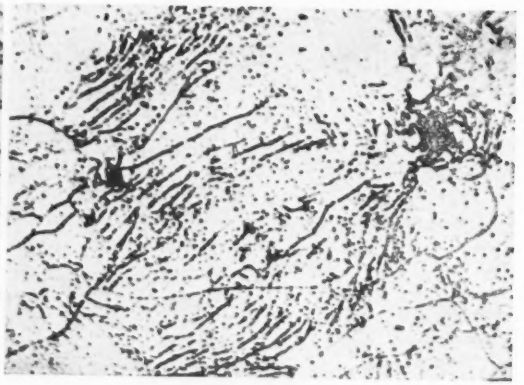
(*b*) 1100° C., W.Q., + 1 week at 500° C., W.Q.



(*c*) 2 hr. at 800° C., W.Q.



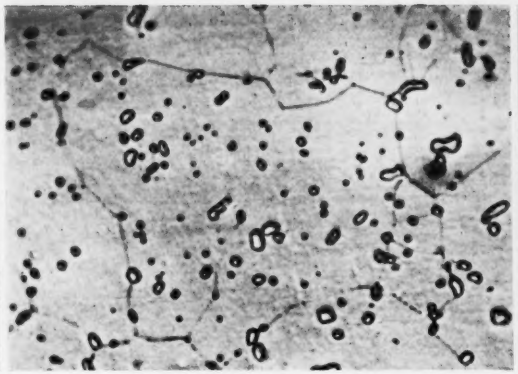
(*d*) 2 hr. at 800° C., W.Q., + 6 months at 475° C., W.Q.



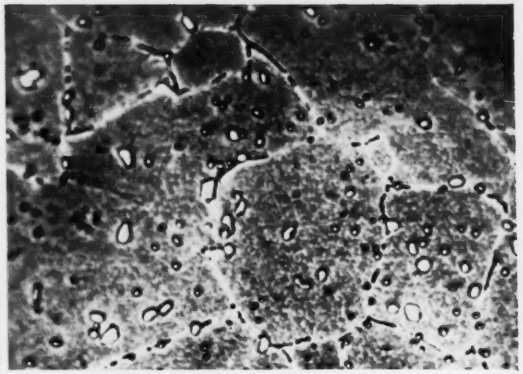
(*e*) 2 hr. at 800° C., W.Q., + 3 months at 500° C., W.Q.

**Fig. 10—Samples of 21% chromium iron, electrolytically polished and (*b*–*e*) subsequently etched for 10 min. in 10% alcoholic HCl. (*a*) and (*b*) Cast 06031; (*c*)–(*e*) cast 06030. × 1500**

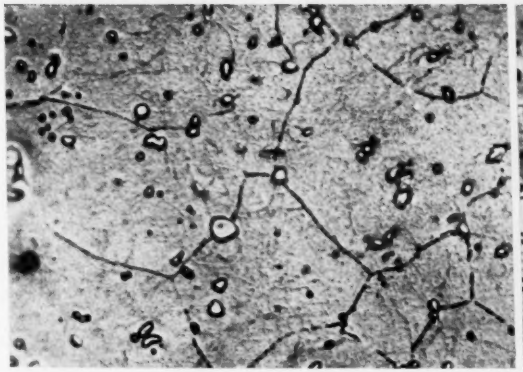
(*a*) 2 hr. at 800° C., W.Q.



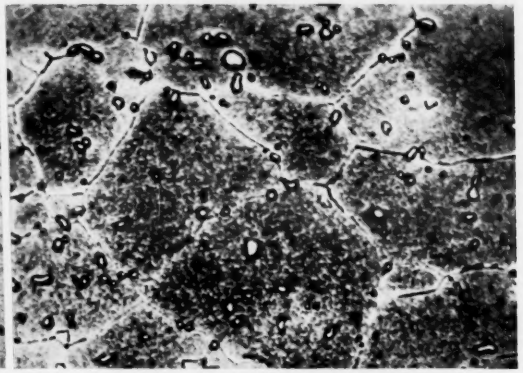
(*b*) 2 hr. at 800° C., W.Q., + 1 month at 475° C., W.Q.



(*c*) 2 hr. at 800° C., W.Q., + 6 months at 475° C., W.Q.

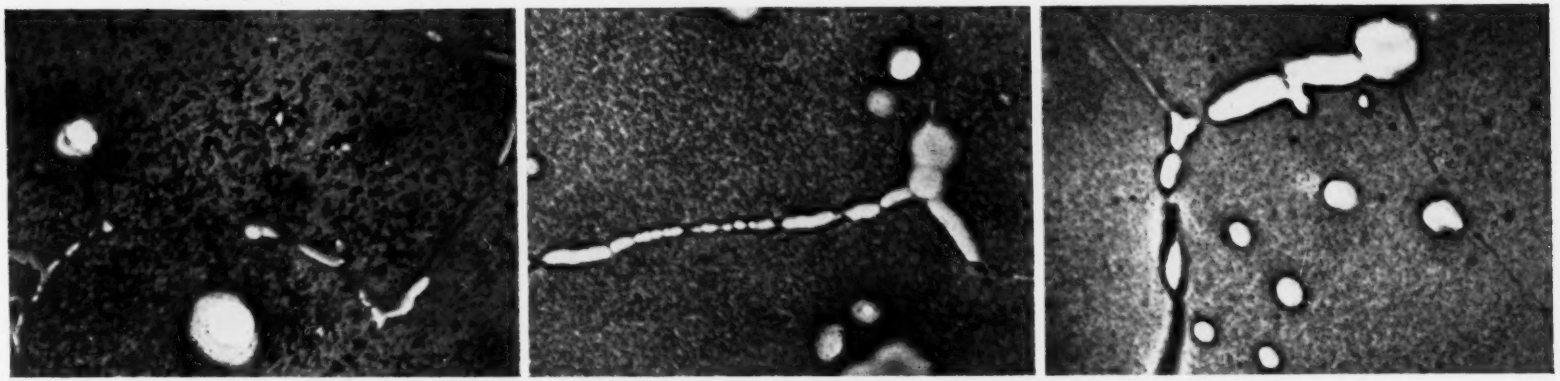


(*d*) 2 hr. at 800° C., W.Q., + 1 month at 500° C., W.Q.



(*e*) 2 hr. at 800° C., W.Q., + 6 months at 500° C., W.Q.

**Fig. 11—Samples of 30% chromium iron (cast *XF* 40632), electrolytically polished and etched for 6 sec. in Newdip ($HCl:HNO_3:H_2O$/10:1:9 plus restrainer) × 1500**

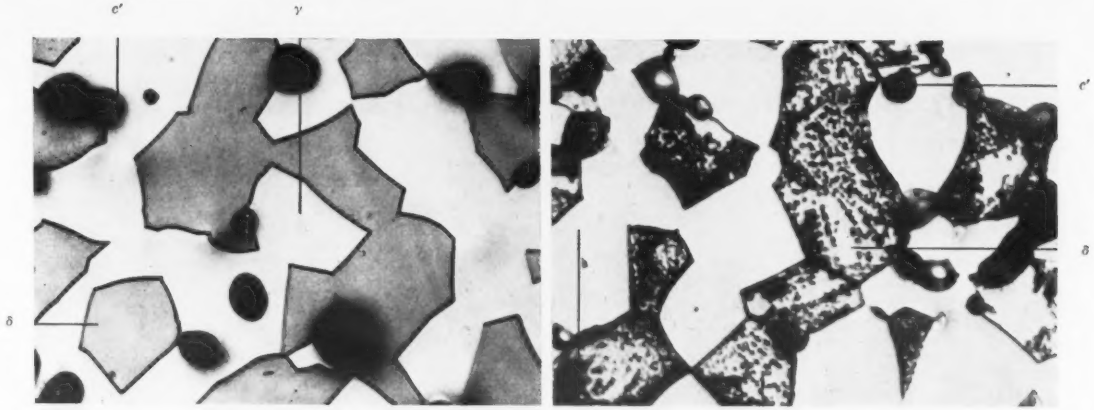


(*a*) 2 hr. at 800° C., W.Q., + 6 months at 475° C., W.Q.

(*b*) 2 hr. at 800° C., W.Q., + 1 month at 500° C., W.Q.

(*c*) 2 hr. at 800° C., W.Q., + 6 months at 500° C., W.Q.

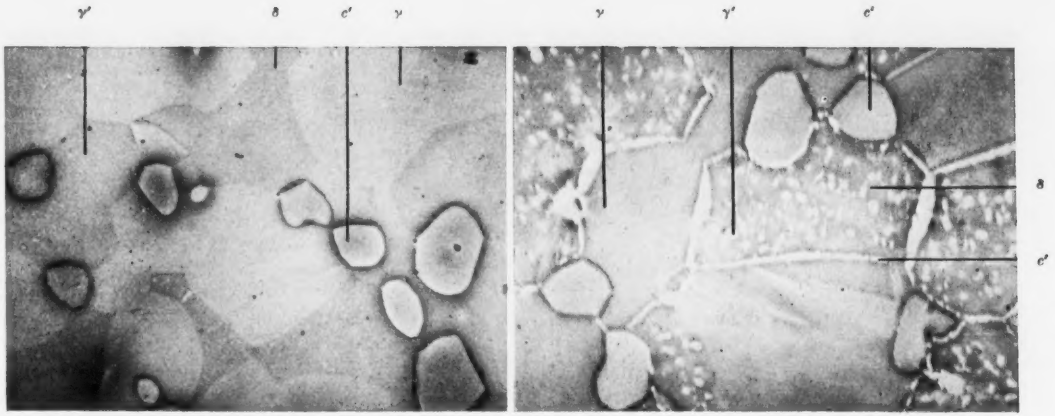
**Fig. 12—Samples of 30% chromium iron (cast *XF* 40632), electrolytically polished and etched for 6 sec. in Newdip × 7500**




(*a*) 1 hr. at 1150° C., W.Q.

(*b*) 1 hr. at 1150° C., W.Q., + 1 week at 475° C., W.Q.

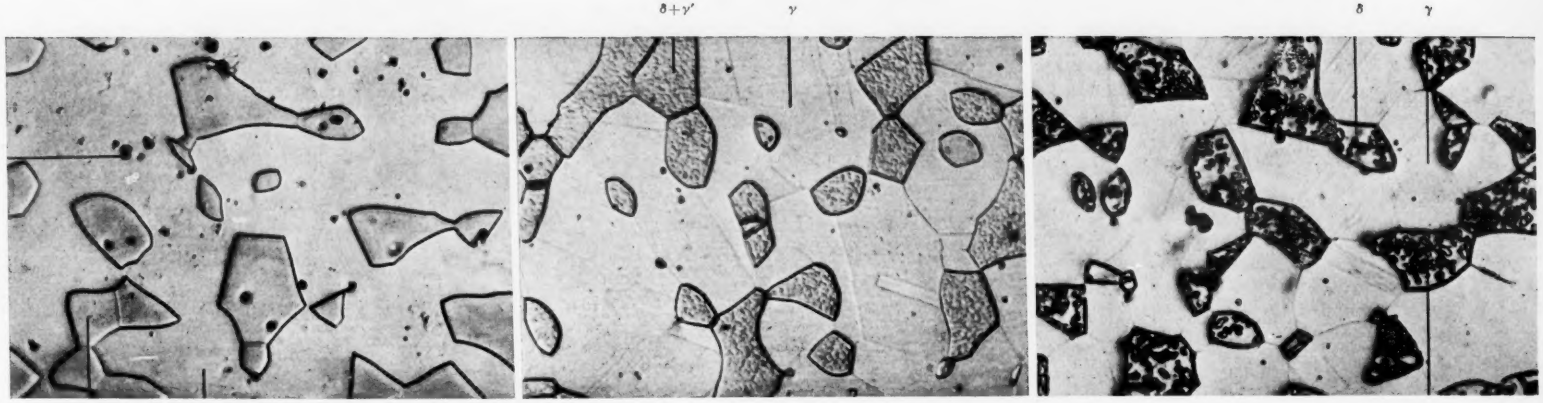
**Figs. 13*a* and *b*—Samples of steel 24/5/Mo, electrolytically polished and etched electrolytically in 10% aqueous oxalic acid × 1500**




(*c*) 1 hr. at 1050° C., W.Q., + 5 weeks at 475° C., W.Q.

(*d*) 1 hr. at 1150° C., W.Q., + 1 month at 600° C., W.Q.

**Figs. 13*c*. and *d*—Samples of steel 24/5/Mo, electrolytically polished. No etch given × 1500**




(*a*) 1 hr. at 1050° C., W.Q., + 1 week at 450° C., W.Q.

(*b*) 1 hr. at 1050° C., W.Q., + 1 week at 500° C., W.Q.

(*c*) 1 hr. at 1050° C., W.Q., + 1 week at 550° C., W.Q.

**Fig. 14—Samples of steel 18/8/Mo/Ti (cast *X*), electrolytically polished and etched electrolytically in 10% aqueous oxalic acid. × 1500**

1 month at 475° and 550° C. These temperatures approximately represent the 'secondary' hardness maximum and the hardness minimum between the two maxima, respectively, as shown in Fig. 1. The results for 18/8/Mo/Ti and 18/8/Mo after 475° and 550° C. treatments are given in Table III.

Table IV gives the mechanical properties of the 18/8/Mo/Ti steel (cast *X*) before and after exposure for 1 month at 450° C.

If the tensile results in Table IV are compared with those for comparable treatments in Table III, a marked similarity will be observed. The decrease in impact properties was likewise similar for the two casts, as shown in Fig. 9.

Tensile and impact properties determined on the 18/8/Mo/Ti and 18/8/Mo alloys after treatment for periods up to 1 month at 475° and 550° C. showed an increase in tensile stress and decrease in ductility and impact properties. The changes were more marked if the treatment was longer and the temperature was lower. They were also more marked for the titanium-stabilized material. These results are in keeping with the higher δ-ferrite content of the 18/8/Mo/Ti alloy, a factor which has already been noted. All the changes in mechanical properties observed are in keeping with the hardness results and indicate the similarity to fully ferritic chromium irons. No explanation can yet be offered for the slight decrease in the value of the limit of proportionality in both duplex alloys after treatment for 1 month at 475° C. and 550° C., although not in the 18/8/Mo/Ti alloy (cast 09482) at 550° C.

## MICROSTRUCTURAL CHANGES OBSERVED AT SECONDARY HARDENING TEMPERATURES

### Fully Ferritic Alloys

*21% Cr Iron*—As-quenched from 1100° C., this alloy had the microstructure shown in Fig. 10*a*, consisting of very fine precipitated carbides in an almost fully ferritic matrix. Traces of austenite, about 1% in amount, were occasionally observed at the grain boundaries. Elsewhere, the latter were outlined by a carbide precipitate. Subsequent exposure of the sample for 1 week at 450° and 500° C. resulted in the appearance of a more intense fine precipitate, and also of a constituent in Widmanstätten form; etching indicated that the precipitate was probably a carbide. A typical structure is shown in Fig. 10*b*. Exposure at 550° C. also produced further precipitation, although less in Widmanstätten form. A softening treatment of 2 hr. at 800° C., W.Q., or 1 hr. at 900° C., W.Q., resulted in the coalescence of many of the fine particles precipitated on water-quenching from 1100° C. A prior treatment of 2 hr. at 800° C., W.Q., after rolling, resulted in the structure shown in Fig. 10*c*, in which a certain amount of precipitation (carbides) is visible on the crystallographic planes. Subsequent exposure at 475° and 500° C. gave a certain amount of oriented precipitate similar to that in the sample pretreated at 800° C., which tended to become spheroidized with ageing time. Intense fine precipitation was observed after 6 months at 475° C., as in Fig. 10*d*, although not after 1 month. Whilst 2 months at 500° C. produced little change in structure, a sample aged for 3 months revealed the presence of recrystallized grains, and also a lamellar structure (*see* Fig. 10*e*). Similar structures were observed at 525° C. after 13 days.

The 21% Cr iron aged for 1 week at 450–900° C., after a prior treatment of ¼ hr. at 1100° C., W.Q., showed a Widmanstätten precipitate at least below about 650° C. That it was observed both above and at secondary hardening temperatures suggests that it was not primarily associated with the hardening process. Its etching characteristics, however, were somewhat anomalous, so that for the moment its identification is obscure. A similar type of precipitation reported recently[18] in 12–16% chromium steels after high-temperature quenching (1100–1300° C.) followed by annealing for 1 hr. at 650–790° C. was attributed to chromium carbide. The lamellar structure observed in samples aged at 500° and 525° C. at points on the hardening curves corresponding to marked softening of the samples, and also observed by Bandel and Tofaute[6] after 1000 hr. at 475°, 500°, and 525° C. in an 18% Cr iron, is interpreted as a form of recrystallization,[19] and, together with the more normal recrystallization observed in these samples, this would explain the softening observed.

*30% Cr Iron*—Treatment of 2 hr. at 800° C., W.Q., resulted in many coalesced carbide particles uniformly distributed in a fully ferritic matrix, as in Fig. 11*a*. Treatment of samples in this condition for up to 6 months at 475° C. resulted in the formation of a precipitate at the grain boundaries and a gradual darkening in the etching characteristics of the matrix. Typical structures are shown in Figs. 11*b* and *c*. Similar structures were observed at 500° C., as shown in Figs. 11*d* and *e*. Both features were more pronounced at the higher ageing temperature. Although the grain-boundary precipitate had the etching characteristics of sigma (*i.e.*, it was attacked by *aqua regia* and unaffected by 10% HCl in alcohol), a phase

**Table IV**

**TENSILE PROPERTIES OF STEEL 18/8/Mo/Ti (CAST *X*)**

| Heat Treatment | Limit of Proportionality | Proof Stress | | | Maximum Stress | Elongation, % | Reduction in Area, % | Izod, ft.lb. |
|---|---|---|---|---|---|---|---|---|
| | | 0·05% | 0·10% | 0·50% | | | | |
| | Tons/sq. in. | | | | | | | |
| 1 hr. at 1100° C., W.Q. | 8·2 | 13·4 | 16·4 | 23·2 | 40·2 | 53·5 | 71·5 | 138 |
| 1 hr. at 1100° C., W.Q., + 1 month at 450° C., W.Q. | 7·8 | 13·8 | 16·3 | 28·4 | 52·1 | 38·0 | 61·5 | 48 |

unmistakably present and identified after ageing at 550–750° C., the cause of the attack on the matrix could not be easily determined in the optical micrographs, the indication being that microstructural changes of a very fine order had occurred.

An electron micrograph of a sample exposed for 6 months at 475° C. confirmed the existence of a grain-boundary precipitate, and showed the attack on the matrix to consist mainly of very fine pits; this is shown in Fig. 12*a*, which also revealed a small amount of a constituent in relief in the matrix. Electron micrographs of samples exposed for 1 and 6 months at 500° C. (*see* Figs. 12*b* and *c*) showed features similar to the 6 months at 475° C. sample, save that in the former the relief constituent in the matrix was more marked and the pits were finer, especially after 6 months at 500° C. All three electron micrographs suggest the existence of very small local regions of different composition, such as would be produced by a very fine precipitate or by a stage just before such precipitation. This effect could possibly be associated with a chromium carbide.

**Duplex Alloys**

*24/5/Mo*—As-quenched from 1050° C., the microstructure of this alloy consisted of about equal proportions of δ-ferrite and austenite, with undissolved chromium carbides occurring mainly in the γ areas. After 1 week at 450–600° C., groups of fine particles were observed in the δ-ferrite zones. These particles, elsewhere[3] shown to be γ′,* increased in amount and size with increasing temperature. The microstructures of samples in the 1150° C., W.Q., and 1 week at 475° C., W.Q., conditions are shown in Figs. 13*a* and *b*. Little further change in microstructure was observed, even after 5 weeks at 475° C. An electron micrograph of a sample in this condition of heat-treatment is shown in Fig. 13*c*, in which the γ′ particles are just visible within the δ-ferrite zones. Figure 13*d* is an electron micrograph of a sample given 4 weeks at 600° C. The γ′ particles are seen to be larger in the 600° C. than in the 475° C. treated sample, and, in addition, the former contains a carbide precipitate at the δ-ferrite–austenite boundaries. The γ′ particles tended to be attacked at their boundaries by 10% aqueous oxalic acid used electrolytically, and were also lightly stained by Murakami's reagent.

*18/8/Mo/Ti*—The microstructure of this alloy as-quenched from 1050° C. was also duplex (γ + δ), about 25% of δ (determined by point counting[17]) being present, with a few fine undissolved titanium-carbide particles present, mainly in the γ areas. After 1 week at 450° or 475° C., no change could be detected in the microstructure, shown in Fig. 14*a*. Treatment at 500° and 550° C. gave microstructures similar to those obtained at corresponding temperatures in steel 24/5/Mo. Etching electrolytically with 10% oxalic acid seemed to attack the δ-ferrite–precipitate interfaces and δ–γ boundaries (*see* Figs. 14*b* and *c*). The identification of the precipitate in 18/8/Mo/Ti will be discussed later. Its etching characteristics were similar to those obtained in the 24/5/Mo alloy.

* Austenite of different composition from that formed at 1050° C. and formed by transformation from δ-ferrite below this temperature.

*18/8/Mo*—This alloy showed microstructural features similar to those observed in 18/8/Mo/Ti, save that about only 5% of δ-ferrite was present after quenching from 1050° C.

*18/8/Ti*—As water-quenched from 1050° C., this alloy showed a duplex microstructure (containing about 5–10% of δ-ferrite) with many fine undissolved and precipitated titanium-carbide particles in the γ matrix. In this alloy, microstructural changes occurred at the δ–γ boundaries, a few very fine particles being precipitated at 475° and 500° C. At 550° C., this effect was more marked, and at 600° C. a precipitation effect was also observed throughout the δ pools.

Although the 24/5/Mo alloy showed the presence of many fine γ′ particles in the δ-ferrite areas after 1 hr. at 475° C., a similar structure was observed after periods up to 6 months at the same temperature. The mechanism of the transformation δ-ferrite → γ′ in this alloy has been explained elsewhere.[3] Likewise, at higher temperatures, such as 550° and 600° C., the 24/5/Mo alloy showed considerable γ′ to have formed, even after very short periods, such as 16 hr., at these temperatures. Since γ′ has formed to this extent without causing any appreciable hardening, it cannot be the cause of the hardening observed at the lower temperatures. Furthermore, there would be no tendency for its formation in the 20% and 30% Cr iron.

The attack on the γ′ particles by oxalic acid and their light staining by Murakami's reagent are considered to be significant. The attack by the oxalic-acid reagent might indicate either the presence of another phase precipitated alongside or within the γ′ particles, or some change in composition of the matrix immediately adjacent to the γ′. One of the authors has elsewhere[3] shown that for γ′ to form in the δ-ferrite regions of the 24/5/Mo alloy, diffusion of chromium must occur away from the potential transformation site. This would result in the eventual γ′ particles being surrounded by chromium-rich δ-ferrite which, as such, or after transformation to σ, would be more susceptible to attack by oxalic acid than the original δ-ferrite. The fact that Murakami's reagent stained the γ′ particles would suggest that the latter were in fact duplex, γ′ + chromium-rich δ, or γ′ + σ, or possibly even γ′ + chromium-rich δ + σ. In annealed filings of 24/5/Mo and 18/8/Mo/Ti, σ could not be detected by X-ray powder techniques (capable of detecting 1% of any phase present), showing the amount of σ present, if any, to be $< 1\%$. This would be the order of the amount present in a block sample such as was used for micro-examination. It affords further proof that what have been termed γ′ particles in the δ-ferrite zones were not in fact σ, since the amount of γ′ present was often in excess of 10%. Similar explanations hold for the microstructural changes observed in the other duplex alloys.

**Consideration of Micro-Examination Results**

A study of the corresponding microstructural characteristics of some of the alloys did not give as fine an indication of the several stages of the 475° C. phenomenon as the hardness and resistivity results.

Thus, although the fully ferritic 30% Cr alloy showed the formation of a grain-boundary precipitate

at 475° and 500° C., as observed by other workers,[7] and here proved to be σ (at least at 500° C.), optical and electron microscopy revealed an increasing attack on the matrix of the grains with ageing time at 475° and 500° C., which has been interpreted to indicate the presence of small local regions of varying composition, probably Cr-enriched and Cr-impoverished zones. No resolvable precipitate could be clearly detected. A similar attack on etching was observed by Bandel and Tofaute[6] and Newell,[9] who attributed the observed microstructural effects to a type of precipitation and sub-microscopic precipitation respectively. The duplex alloys also showed no new phase that could account for the changes in mechanical properties on ageing, but they did indicate the formation of Cr-rich and Cr-impoverished zones.

## RESULTS OF X-RAY EXAMINATION

### Examination of Powder Samples

*Fully Ferritic Alloys*—The work was here confined to the 30% chromium alloy, and the results are given in Table V. Although annealed filings did not show the presence of a new phase or any change in the intensity or breadth of the diffraction lines for periods up to 1 month at 400–550° C., non-annealed filings showed σ to have formed at 475°, 500°, 525°, and 550° C., and increasing stress relief of the ferrite to have occurred with increasing temperature.

*Duplex Alloys*—As annealed, 24/5/Mo and 18/8/Mo/Ti filings showed only γ + ferrite + carbides after 1 week and 1 month at 475° C. As filed, these alloys showed the same phases as annealed filings after 1 month at 475° and 500° C., but σ was clearly detected after 1 month at 550° and 600° C.

### Grazing Incidence Techniques on Micro-Samples

*Fully Ferritic Alloys*—Using Cr X-radiation, no phase other than ferrite could be detected in the 30% Cr iron after 1 month and 6 months at 475° C.; similar results were obtained in a sample given 1 month at 500° C., using filtered Mn X-radiation in conjunction with a single-crystal monochromator. Ferrite and weak sigma reflections (using Cr X-radiation) were observed in a 30% chromium sample given only 1 week at 600° C.

*Duplex Alloys*—Using filtered Co X-radiation, only γ + ferrite could be detected in 18/8/Mo and 18/8/Mo/Ti samples after 1 week at 450° and 550° C. respectively; the use of a monochromator with Mn radiation revealed only γ + ferrite + $(Cr,Fe)_{23}C_6$ in the 24/5/Mo alloy after 1 week at 450°, 500°, 550°, and 600° C., and also after 1 month at 600° C.

### Identification of Powder Residues

Residues were obtained only from the 24/5/Mo alloy, after treatment of bar samples for 1 month at 475° and 600° C. Sigma and $(Cr,Fe)_{23}C_6$ were detected in the residues of both samples.

### Resistivity Tests

A series of 30% Cr iron samples were treated for varying times at 375°, 400°, 475°, and 525° C. Hardness measurements were also made on the resistivity bars for comparison. Graphs of resistivity and hardness are given in Fig. 15. The changes in resistivity with time at any temperature are exactly the reverse

## Table V

### RESULTS OF X-RAY EXAMINATION OF 30% CHROMIUM ALLOY FILINGS AFTER AGEING

| Ageing Temp., °C. | Pre-Treatment of Filings | Phases Detected by X-Ray Diffraction — Ageing Period | | | Effect of Ageing on X-Ray Line Breadth |
|---|---|---|---|---|---|
| | | 1 Day | 1 Week | 1 Month | |
| 400 | Annealed | Ferrite | Ferrite | Ferrite | All samples gave sharp reflections |
| | As cold-worked | ... | ... | ... | ... |
| 475 | Annealed | Ferrite | Ferrite | Ferrite | All samples gave sharp reflections |
| | As cold-worked | ... | Ferrite + σ (trace) | Ferrite + σ (*M/S*) | All samples showed slight diffuseness (*i.e.*, incompletely stress-relieved) |
| 500 | Annealed | Ferrite | Ferrite (after 11 days) | Ferrite | All samples gave sharp reflections |
| | As cold-worked | ... | Ferrite + σ (*M/S*) | Ferrite + σ (*M/S*) | All samples showed slight diffuseness (*i.e.*, incompletely stress-relieved) |
| 525 | Annealed | Ferrite | Ferrite | Ferrite | All samples gave sharp reflections |
| | As cold-worked | Ferrite + σ (*W*) | Ferrite + σ (*M*) | Ferrite + σ (*M/S*) | All samples showed very slight diffuseness (*i.e.*, almost fully stress-relieved) |
| 550 | Annealed | Ferrite | Ferrite | ... | All samples gave sharp reflections |
| | As cold-worked | ... | ... | Ferrite + σ (*M/S*) | Samples gave sharp reflections (*i.e.*, fully stress-relieved) |

*W* = Weak *M* = Medium *M/S* = Medium/Strong

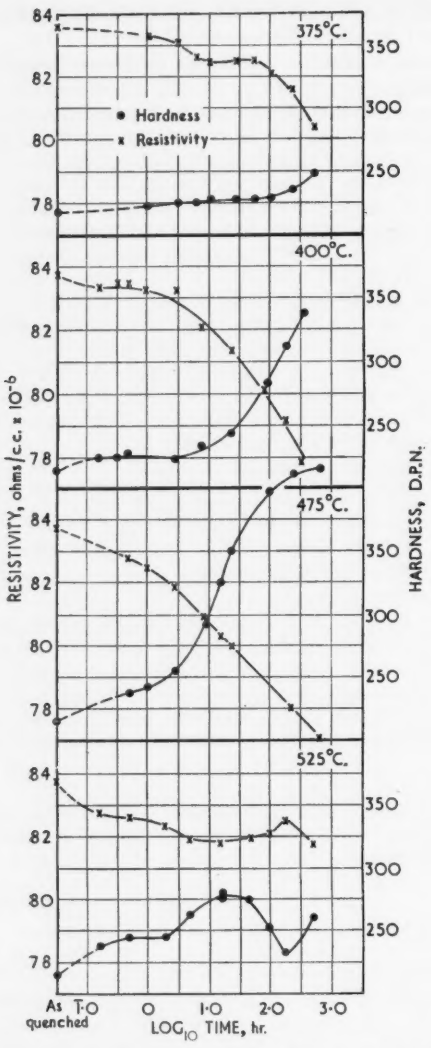



**Fig. 15—Effect of time at temperature on electrical resistivity of 30% Cr iron**

of those in hardness. No initial increase in resistivity was observed at any of the temperatures examined for holding periods as short as 10 min.

### Magnetic Properties

Two 30% Cr iron samples were softened (2 hr. at 800° C., W.Q.) and treated for 1 day and 10 days at 475° C. The 475° C. treatment resulted in an increase in magnetic induction in line with the results obtained by Bandel and Tofaute.[6] This increase would not be inconsistent with the precipitation of a limited quantity of a non-magnetic Cr-rich phase due to the matrix becoming iron-enriched.

## GENERAL DISCUSSION

Perhaps the most significant observation in the present investigation is the similarity between duplex ($\gamma + \delta$) high alloys and those of the fully ferritic ($\delta$) type with respect to the changes in mechanical properties occurring in both after treatment at about 475° C. The observed increase in hardness and tensile strength and the decrease in ductility and impact properties suggested that duplex high alloys can display the phenomenon commonly known as '475° C. embrittlement,' although not to such a marked extent as the fully ferritic steels. It is now well established[1–3, 20] that duplex alloys of the 18/8/Mo/Ti (or Nb) and 24/5/Mo type can be embrittled by treatment at about 600–850° C., the embrittlement being due to the visible precipitation of hard massive $\sigma$ particles. Fully austenitic alloys of the 24% Cr, 21% Ni and 18% Cr, 10% Ni, Nb-bearing types are also known to form $\sigma$ within about the same temperature range, as shown by work carried out in America and in the United Kingdom.[12, 21] Thus, apart from the 18/8 alloy, in which no $\sigma$ was suspected, all the duplex and fully austenitic alloys examined are of the type that can form $\sigma$ at moderately elevated temperatures (about 550–850° C.). The formation of $\sigma$ in fully ferritic chromium iron has been well established by many workers,[6, 7, 14, 15] the limiting chromium content at which the phase could be formed having been reduced recently[22] to 13% for an exposure temperature of 480° C. It is, therefore, not unreasonable to expect that, under suitable conditions (cold-working and long soaking periods), $\sigma$ can also form or tend to do so at even lower temperatures in all the alloys studied. Extrapolation of Cook and Jones's[15] $\alpha - (\alpha + \sigma)$ phase boundary at the iron-rich side of the Fe–Cr phase diagram below the limit of 26% chromium at 600° C. gives the phase boundary at about 20% chromium at 475° C. Furthermore, Shortsleeve and Nicholson[23] have recently shown that silicon and manganese in amounts normally present in ferritic chromium steels have the effect of displacing the $\alpha - (\alpha + \sigma)$ phase boundary towards lower values of chromium content. In the duplex alloys, the $\delta$-ferrite, by being enriched with ferrite-forming elements such as molybdenum, titanium, and silicon, apart from chromium, would tend to form $\sigma$ more easily. The occurrence of $\sigma$ in the alloys at 475–600° C. or the tendency towards its formation at these and even lower temperatures would seem to be fully in accord with theoretical expectations. The nature of the hardness/log-time curves for duplex alloys treated at temperatures up to about 525° C., and a comparison of the relative hardening and embrittling effects at 475° and 550° C., suggest, however, that the changes in mechanical properties observed at 550° C. and above are due to a mechanism different from that affecting the mechanical properties below 550° C. The present work has established that the extent of 475° C. embrittlement in these alloys is related to the $\delta$-ferrite content, whether for different alloys or for the same alloy, and that as the amount of $\delta$ present increases, the changes in mechanical properties observed become greater. There would also seem to be a similar relationship between these changes and the chromium content of the ferrite, although this can be established on a firm quantitative basis only for the fully ferritic alloys. These relationships between the extent of 475° C. embrittlement and (*a*) the $\delta$-ferrite content of the alloy and (*b*) the

chromium content of the δ-ferrite, should be important in explaining the cause of this embrittlement.

The work described in the present paper throws little fresh light on the difficult problem of the mechanism of 475° C. embrittlement. Of many investigations,[4–11] probably the most comprehensive is that of Bandel and Tofaute,[6] who suggested that the hardening process was similar to that in aluminium–copper at room temperature, in which copper-rich 'nuclei' of precipitate have formed, but still on the lattice of the solid solution. The experiments on retrogression described in the present paper tend to support this view.

However, the observed decrease in electrical resistance is the opposite of what would be expected on their hypothesis. In aluminium–copper alloys, pre-precipitation is accompanied by an increase in electrical resistance; a decrease in resistance usually indicates the formation of separate crystals of the precipitate.[24]

The 475° C. embrittlement seems to be associated in some way with the σ phase, in that it occurs over the range of compositions where σ might be expected to form (if diffusion was sufficiently rapid) from the established phase boundaries at higher temperatures. Bnt an explanation in terms of actual precipitation of σ seems to be very improbable, in view of the temperature interval between 475° C. embrittlement and precipitation of σ from about 550° C. upwards. In addition, no trace of a precipitated phase was detected, in the present investigation, in the examination of a fully hardened 30% Cr–Fe alloy, using monochromatic X-radiation, by which means 1% of a second phase may be detected. Assuming a hardness of 800 D.P.N. for the σ phase, the presence of 30% of σ would be required to explain the observed hardness increase of the 30% Cr–Fe alloy.

## CONCLUSIONS

(1) The development of '475° C. embrittlement' has been confirmed in 21% and 30% Cr irons and has also been observed in duplex alloys of the 24/5/Mo, 18/8/Mo/Ti, 18/8/Mo, and 18/8/Ti types. It was not observed in fully austenitic alloys of the 18/8 and 18/10/Ti types, although there was a suggestion of its presence in a 24/21 alloy.

(2) The phenomenon has been shown to be accompanied by a hardening process, the latter being observed at temperatures in the ranges 375–525° C. and 350–525° C. for the fully ferritic and duplex alloys, respectively. Maximum effects were found at 475–500° C. for the periods investigated.

(3) A limited number of mechanical tests confirmed the expected increase in tensile strength and the decrease in ductility and impact strength with ageing at these temperatures.

(4) Resistivity and magnetic measurements and X-ray results did not reveal any stresses in the matrix accompanying the ageing process, but the first two techniques did indicate a continuous change (alloy depletion) in the composition of the matrix. Although this could be attributed to the segregation of chromium from the matrix to form a second phase, no such phase could be detected.

(5) The extent of secondary hardening was observed to increase with the percentage of δ-ferrite present in the duplex alloys, and with the percentage of chromium content in the fully ferritic alloys.

(6) X-ray work has shown that σ can form in a 30% Cr iron after cold-working by filing and in the duplex 24/5/Mo alloy at as low a temperature as 475° C., and at 550° C. in the 18/8/Mo/Ti alloy.

(7) The formation of σ at 550° C. and below in all the alloys exhibiting secondary hardening is in accord with theoretical expectations, but an explanation of the hardening in terms of actual precipitation of σ seems to be improbable.

(8) Further work is required to establish the precise mechanism of 475° C. embrittlement.

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# Tensile and Impact Properties of High-Purity Iron–Carbon and Iron–Carbon–Manganese Alloys of Low Carbon Content

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SYNOPSIS

The tensile and impact properties of iron–carbon alloys of low carbon content and of some iron–carbon–manganese alloys at various temperatures spanning the tough-to-brittle transition have been measured for various heat-treatments above and below the $A_1$ point. It is shown that the rate of cooling from the austenitic region has a large effect on the properties obtained. A fast rate of cooling that favoured retention of carbon in solution (but also decreased the grain size) generally gave improved proof stress and tensile strength, a higher cleavage strength at −196° C., and a lower temperature of transition from tough to brittle fracture in the Charpy impact test. On water-quenching, a good combination of tensile and impact properties was obtained at a carbon level of about 0·05%, but still further improvement was obtained by adding manganese. Water-quenching iron–carbon alloys containing up to about 0·006% of carbon resulted in intergranular brittleness and a deterioration in properties. A slower rate of cooling that produced carbide films at grain boundaries and around areas of pearlite gave high impact transition temperatures. This is associated with the production of cracks in the carbide, which are considered to initiate cleavage of the ferrite at a temperature at which it should be ductile in the absence of the carbide films. The shape of the impact-value/temperature curve was modified when carbide films were present in the microstructure. Sufficient manganese prevented the formation of carbide films and gave a more or less sharp transition from tough to brittle fracture in impact. Some evidence is presented which suggests that the quench ageing of iron–carbon alloys, which involves a rise in impact transition temperature, is at least retarded by manganese. An extensometer that is not damaged when a tensile test piece breaks in a brittle manner at low temperatures is described. Electron microscope pictures are presented to show the changes during ageing. 761

WORK at the National Physical Laboratory on the effect of alloying elements on the mechanical properties of ferrite, over a temperature range covering the transition from a tough to a brittle fracture, has emphasized the large effects produced by small quantities of certain elements, such as carbon, oxygen, and nitrogen, compared with those of the usual substitutional alloying elements, such as chromium and molybdenum. It seemed, in certain cases, that the importance of an alloying element lay, initially at least, in its effect on the small quantities of elements such as carbon, oxygen, and nitrogen that might also be present in the alloys.

The overriding influence of oxygen in proportions greater than about 0·003% for the conditions under which iron was made in this work has already been described[1,2]. The present paper is concerned with the effect of small amounts of carbon on the properties of iron, and with the changes that can be brought about by simple heat-treatments; the effects produced by manganese at two carbon levels are also considered.

The tensile and impact properties of iron–carbon alloys containing 0·01%, 0·03%, and 0·05% of carbon, those of iron–0·05% carbon alloys with 0·5%, 1%, and 2% of manganese, and those of an iron–0·03% carbon alloy with 2% of manganese, have already been discussed by Rees, Hopkins, and Tipler[1] for the normalized condition. In view of the large effects obtained with carbon in a certain range, this work has been extended to cover alloys with more closely spaced carbon contents. Since the proportion of carbon retained in solution appeared to be an important factor in governing the transition temperature, the effects brought about by heat-treatment have been studied. The effect of heat-treatment on the iron–carbon–manganese alloys mentioned above has also been included in this work.

## PREPARATION OF ALLOYS

A series of high-purity alloys with carbon contents ranging from 0·0025% to 0·117% was made in the form of 25-lb. ingots by a procedure that has already been described[3]. Swedish iron, previously oxidized

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by melting in air, was remelted *in vacuo* and treated with dried hydrogen at atmospheric pressure to remove oxygen. Carbon was added to the molten iron after the hydrogen pressure had been reduced to 5 cm. of Hg immediately before it was cast into heavy chill moulds to give octagonal ingots 10½ in. long without the feeder head, and 2¾ in. across the flats. The ingots were hot-rolled to ⅝-in. dia. bars and normalized by heating to 950° C. for a short time followed by air-cooling.

In making the iron–carbon–manganese alloys, electrolytic manganese was added after the oxygen in the iron had been reduced, but the hydrogen treatment was continued so as to remove the small amount of oxygen present as oxide on the surface of the manganese. Carbon was added immediately before casting, as for the iron–carbon alloys, to minimize reduction of the alumina melting crucibles, with resultant contamination of the alloys by aluminium.

The carbon was in the form of Hilger H.S. electrodes, and the electrolytic manganese had the following main impurities:

| C, % | Si, % | S, % | P, % | Ni, % | Cu, % | Fe, % |
|---|---|---|---|---|---|---|
| 0·008 | 0·003 | 0·024 | 0·002 | <0·001 | <0·001 | 0·001 |

The analyses of the alloys are given in Table I. The impurities throughout the two series of alloys were low and uniform in amount.

## TESTING AND HEAT-TREATMENT

Tensile tests were carried out at room temperature and −196° C. in a hydraulically operated testing machine on 0·282-in. dia. test pieces with a gauge length of 1 in., and ½-in. B.S.W. rolled threads. Proof stresses were determined by means of an extensometer that was not damaged if a test piece fractured in a brittle manner. A brief description of the extensometer is given in Appendix I.

Impact tests were carried out over a range of temperature spanning the tough-to-brittle transition on standard-size Charpy test pieces having an Izod V-notch. Where the transition was not sharp, the transition temperature was taken as being the temperature at which the impact value reached half that in the fully tough condition.

The first batch of heat-treatments, consisting of furnace-cooling, air-cooling, and water-quenching from 950° C., was carried out with the test pieces sealed in evacuated silica tubes or in an evacuated furnace. The second batch of heat-treatments, carried out on the Fe–C alloys only, consisted of (*a*) furnace-cooling from 950° C. followed by water-quenching from 700° C., and (*b*) water-quenching from 950° C. followed by furnace-cooling from 700° C. The time at 950° C. was kept short (about 10 min.) to avoid excessive grain growth, whereas the time at 700° C. was 1 hr. The average furnace-cooling rate was 1° C./min. from 950° to 700° C., with a total time of 4½ days to reach room temperature. The notches in the Charpy test pieces were machined after heat-treatment. Tests were usually done well within 24 hr. of the heat-treatment, to avoid quench-ageing effects.

The grain sizes of the two sets of alloys after the various heat-treatments are given in Table II.

## PROPERTIES OF IRON–CARBON ALLOYS HEAT-TREATED AT 950° C.

The tensile properties at room temperature of the iron–carbon alloys after furnace-cooling, air-cooling, and water-quenching from 950° C. are given in Fig. 1*a*, and those at −196° C. in Fig. 1*b*.

In the tests at room temperature, all the alloys gave a yield in the furnace-cooled condition, and all except one gave a yield in the air-cooled condition, but no yield was obtained in any of the alloys after water-quenching. The effect of increasing carbon content on the yield stress and tensile strength was small in the alloys in the furnace-cooled condition, but it was more marked in the air-cooled condition. The effect of increasing carbon content on the 0·5% proof stress and tensile strength in the water-quenched condition was very pronounced, the values for the

## Table I

### CHEMICAL ANALYSES OF ALLOYS USED

| Alloy No. | C, % | Si, % | Mn, % | S, % | P, % | Ni, % | Cr, % | Cu, % | Al, % | O, % | N, % | H, % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 53*AF*1 | 0·0025 | 0.003 | <0·005 | 0·004$_6$ | 0·001 | 0·007 | 0·001 | 0·005 | 0·004 | 0·001 | 0·001 | <0·000005 |
| 57*AF*1 | 0·0042 | 0·001 | <0·005 | 0·003$_5$ | n. d. | n. d. | n. d. | n. d. | 0·001 | 0·002$_6$ | 0·001$_2$ | ,, |
| 58*AF*1 | 0.0053 | 0·001 | n. d. | 0·002$_7$ | n. d. | n. d. | n. d. | n. d. | 0·001 | 0·001$_9$ | 0·002$_1$ | ,, |
| 31*AF*2 | 0·0096 | 0·002 | 0·004 | 0·005$_4$ | 0·0007 | 0·006 | 0·001 | 0·006 | 0·004 | 0·001$_1$ | 0·001$_2$ | ,, |
| 56*AF*3 | 0·011 | 0·001 | n. d. | 0·003$_3$ | n. d. | n. d. | n. d. | n. d. | 0·002 | 0·001$_2$ | 0·001$_2$ | ,, |
| 57*AF*2 | 0·012 | 0·003 | <0·005 | 0·003$_3$ | n. d. | n. d. | n. d. | n. d. | 0·001 | 0·001$_2$ | 0·001$_2$ | ,, |
| 58*AF*2 | 0·013 | 0·002 | n. d. | 0·003$_5$ | n. d. | n. d. | n. d. | n. d. | 0·002 | 0·001$_2$ | 0·001$_4$ | ,, |
| 56*AF*2 | 0·024 | 0.003 | <0·001 | 0·003$_1$ | n. d. | n. d. | n. d. | n. d. | 0·008 | 0·001$_4$ | 0·002$_4$ | ,, |
| 31*AF*1 | 0·028 | 0·002 | 0.004 | 0·006 | n. d. | 0·005 | 0·002 | 0·006 | 0·004 | 0·001 | 0·001$_2$ | ,, |
| 59*AF*1 | 0.040 | 0·001 | n. d. | 0·002$_8$ | n. d. | n. d. | n. d. | n. d. | 0·003 | 0·0007 | 0·001$_7$ | ,, |
| 30*AF*3 | 0·044 | 0·003 | 0·003 | 0·004 | n. d. | 0·005 | 0·002 | 0·006 | 0·004 | 0·0006$_8$ | 0·001$_4$ | ,, |
| 56*AF*1 | 0·117 | <0·001 | 0·001 | 0·003$_8$ | n. d. | n. d. | n. d. | n. d. | 0·006 | 0·0005$_3$ | 0·0009$_8$ | ,, |
| 51*AF*2 (0·05% C–0·5% Mn) | 0·051 | 0·002 | 0·46 | 0·005$_4$ | n. d. | n. d. | n. d. | n. d. | 0·003 | 0·001$_8$ | 0·001$_2$ | ,, |
| 51*AF*1 (0·05% C–1% Mn) | 0·053 | 0·002 | 0·97 | 0·005$_1$ | n. d. | n. d. | n. d. | n. d. | 0·003 | 0·001$_8$ | 0·001 | ,, |
| 32*AF*2 (0·05% C–2% Mn) | 0·046 | 0·005 | 2·04 | 0·007 | n. d. | n. d. | 0·001 | n. d. | 0·003 | 0·0008$_8$ | 0·002 | ,, |
| 32*AF*1 (0·03% C–2% Mn) | 0·032 | 0·005 | 2·00 | 0·007 | n. d. | n. d. | 0·001 | n. d. | 0·003 | 0·0004$_8$ | 0·001$_5$ | ,, |

n. d. = Not determined

## Table II

### FERRITIC GRAIN SIZES OF IRON–CARBON AND IRON–CARBON–MANGANESE ALLOYS

**Average number of ferrite grains per millimetre, determined in two directions at right-angles on longitudinal sections and expressed in A.S.T.M. grain-size numbers; 1–8 correspond to 4, 5·7, 8, 11·3, 16, 22·6, 32, and 45·2 grains/mm. respectively.**

| Alloy No. | Carbon and Manganese Contents | F.C. 950° C. | A.C. 950° C. | W.Q. 950° C. | F.C. 950° C., W.Q. 700° C. | W.Q. 950° C., F.C. 700° C. |
|---|---|---|---|---|---|---|
| 53*AF*1 | 0·0025% C | 2–3 | 2–3 | 3–4 | 2 | 2–3 |
| 57*AF*1 | 0·0042% C | 1–2 | 2 | 3–4 | | |
| 58*AF*1 | 0·0053% C | 2 | 3–4 | 3 | | |
| 31*AF*2 | 0·0096% C | 3 | 3–4 | 4–5 | | |
| 56*AF*3 | 0·011% C | 3 | 4 | 4–5 | | |
| 57*AF*2 | 0·012% C | 3–4 | 4–5 | 5–6 | 3–4 | 5–6 |
| 58*AF*2 | 0·013% C | — | 3–4 | 5–6 | | |
| 56*AF*2 | 0·024% C | 4–5 | 5–6 | — | | |
| 31*AF*1 | 0·028% C | 3–4 | 6 | 7 | | |
| 59*AF*1 | 0·04% C | 3–4 | 6 | | | |
| 30*AF*3 | 0·044% C | 3–4 | 7 | | | |
| 56*AF*1 | 0·117% C | 4–5 | 8–9 | | 3–4 | |
| 51*AF*2 | 0·051% C, 0·46% Mn | 5–6 | 7–8 | | | |
| 51*AF*1 | 0·053% C, 0·97% Mn | 6 | 8 | | | |
| 32*AF*2 | 0·046% C, 2·04% Mn | 8 | >8 | | | |
| 32*AF*1 | 0·032% C, 2·0% Mn | 7 | >8 | | | |

0·117% C alloy being 26·5 and 34·2 tons/sq. in. respectively, compared with 9·2 and 16·8 tons/sq. in. for the iron containing 0·0025% of carbon. In the furnace-cooled condition, the elongation and reduction in area tended to be lowered a little by increasing carbon content, but they became distinct in the air-cooled condition and were again very marked after water-quenching. The alloy with the highest carbon content (0·117%) still had considerable ductility as water-quenched, the elongation being 19% and the reduction in area 66%.

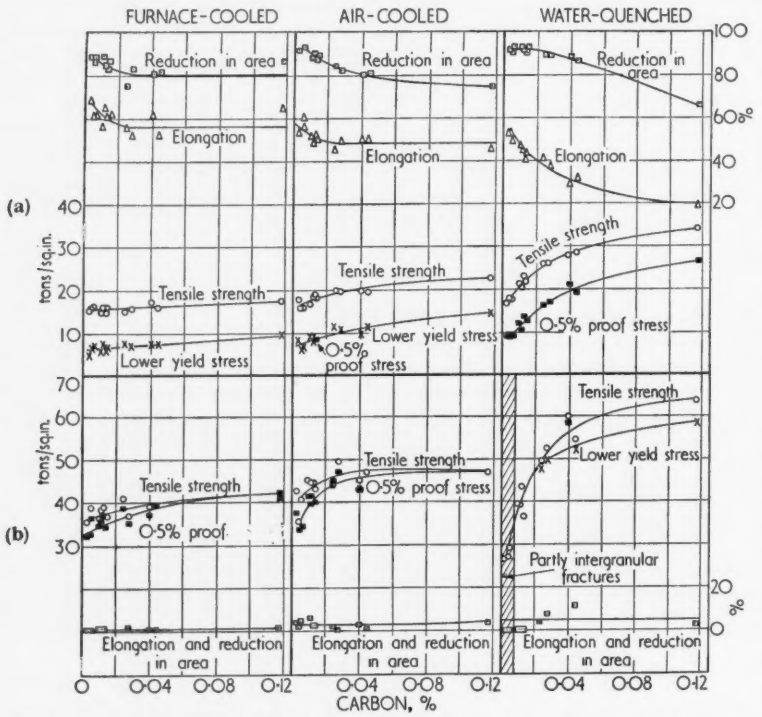



**Fig. 1—Tensile properties at (*a*) room temperature and (*b*) −196° C. of iron–carbon alloys cooled at different rates from 950° C.**

The effect of increasing the rate of cooling from the heat-treatment temperature on the tensile properties at room temperature of any one alloy was to raise the yield (or proof) stress and tensile strength, and generally to lower the elongation. The effect was more marked with higher carbon contents, but it was only just detectable at the lowest carbon level; *i.e.*, at 0·0025% of carbon the only effect of increasing the rate of cooling was a slight increase in proof stress and a small reduction in elongation. The effect of increasing the rate of cooling on the reduction in area was, if anything, to raise it for carbon contents up to 0·044%, but at the highest carbon level of 0·117% it was lowered.

When tested in tension at −196° C., only the highest-carbon alloy (0·117%) gave a yield in the furnace-cooled condition; three out of the five alloys with carbon contents of 0·024% and above gave a yield in the air-cooled condition, whereas four yielded in the water-quenched condition. All the alloys broke with a brittle fracture at −196° C., the elongation and reduction in area being usually no more than a few per cent., although somewhat higher ductility was obtained in some of the alloys in the water-quenched condition. The effect of increasing the carbon content in the furnace-cooled and air-cooled conditions was to raise to some extent the 0·5% proof stress and the tensile strength; the fractures of all the alloys in these two conditions occurred entirely by cleavage. In the water-quenched condition, a small amount of intergranular fracture occurred in the alloys containing 0·0053% and less of carbon, although most of the fractures of these alloys were of the cleavage type. As a result of this, the tensile strengths of the three lowest-carbon alloys (0·0025%, 0·0042%, and 0·0053%) were much lower at 26·7–29·3 tons/sq. in. than in the furnace-cooled and normalized conditions (32·9–42·7 tons/sq. in.). The permanent deformation was also insufficient for the usual proof stresses to be reached, but this is also true of the next three alloys in the series, which showed no significant evidence of intergranular fracture. The reason for the appearance of a small amount of intergranular fracture in the lowest-carbon alloys after water-quenching from 950° C. is not known, but in this connection it will be noted from Table I that the oxygen contents are low. Increasing the carbon content caused a large rise in the 0·5% proof stress and tensile strength of the alloys when in the water-quenched condition.

Apart from the lowest-carbon alloys, which gave partly intergranular fractures on water-quenching, the general effect of increasing the rate of cooling from the heat-treatment temperature was to increase the proof or yield stress and the tensile strength at −196° C. In view of the small reductions in area, the fracture stresses were only a little higher than the tensile strengths, and it can be stated that increasing the rate of cooling also increased the cleavage strength. The effect of heat-treatment on the tensile properties at room temperature and −196° C. is consistent with the fact that increasing rate of cooling from the heat-treatment temperature favours the retention of carbon in solution, but the grain size was also decreased.

In Fig. 2, the Charpy impact transition temperatures of the iron–carbon alloys are plotted against carbon content for the furnace-cooled, air-cooled, and water-quenched conditions. In the furnace-cooled alloys, an increase in carbon content caused a sharp rise in transition temperature from 61° C. for the 0·0025% C alloy to 126° C. for the 0·028% C alloy; further increase in carbon content up to 0·117% caused a small drop in transition temperature to 110° C. In the air-cooled condition, increasing the carbon content up to about 0·01% had little effect, the transition temperature remaining at −10±6° C. An increase in carbon content to 0·028% again caused a sharp rise in transition temperature to 89° C., whereas a further increase to 0·117% resulted in a small lowering of the transition temperature to 60° C. As in the tensile tests at −196° C., the fractures in impact of the brittle test pieces of the three lowest-carbon alloys after water-quenching showed small amounts of intergranular failure, and the transition temperatures were higher than in the normalized condition. For carbon contents in the range 0·01–0·044%, water-quenching resulted in a progressive lowering of the transition temperature to −57° C., but it was then raised to −3° C. with further increase in carbon content to 0·117%.

Apart from the three alloys of lowest carbon content, in which the fractures were to a small extent along the grain boundaries when water-quenched, the fractures of the brittle impact test pieces were entirely of the cleavage type, and the effect of increasing the rate of cooling from the heat-treatment temperature was to lower the transition temperature in impact.

There is a close connection between the impact transition temperature and the appearance of carbide in the microstructure. In the normalized condition, no massive carbide has been seen in the microstructures of the alloys with carbon contents below 0·013%, and in this range the transition temperature remained substantially constant. The microstructure of the 0·01% C alloy is shown in Fig. 8*a*. The subsequent rapid rise in transition temperature occurred over the range of carbon contents (0·013–0·028%) in which carbide first appeared; this is shown at 0·024% of carbon in Fig. 8*b*. The structure of the 0·117% C alloy, consisting of ferrite and pearlite, is shown in Fig. 8*c*. A feature of Figs. 8*b* and *c* is the carbide at grain boundaries and partly around the pearlite areas.

In the furnace-cooled alloys, the transition temperature in impact of the lowest-carbon alloy (0·0025% C) was well above that in the normalized condition, and the rise in transition temperature with increasing carbon content occurred from the start. It is of

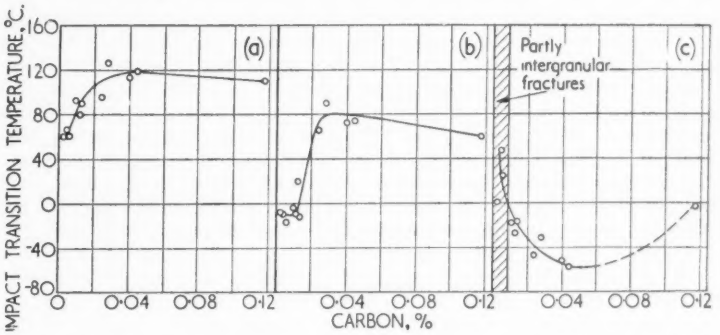



**Fig. 2—Charpy impact transition temperatures of iron–carbon alloys (*a*) furnace-cooled, (*b*) air-cooled, and (*c*) water-quenched from 950° C.**

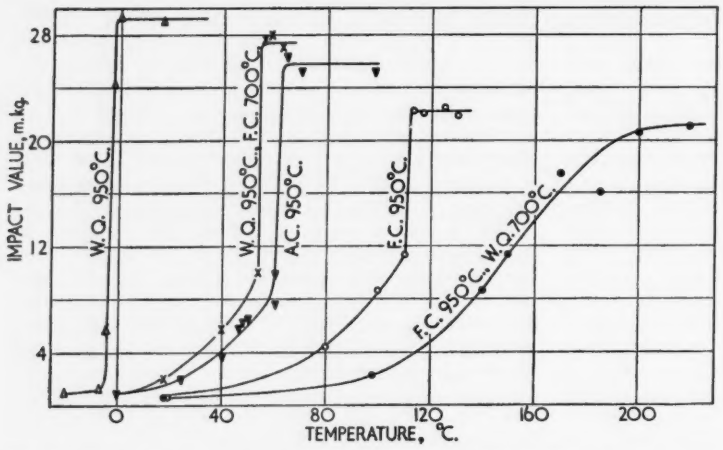



**Fig. 3—Impact-value/temperature curves of 0·117% C alloy after various heat-treatments**

interest that the furnace-cooled 0·0025% C alloy contained a small amount of carbide, as shown in Fig. 9*a*, which agrees with the recent determinations of the solubility of carbon in iron at temperatures down to 150° C. (Wert[4], using a damping method) and down to 350° C. (Borelius and Berglund[5], using a calorimetric method). Increasing the carbon content to 0·028%, which is the range over which the transition temperature rose, resulted in increasing amounts of grain-boundary carbide, the structure of the 0·028% C alloy being as shown in Fig. 9*b*. Further increase in carbon content caused the formation of pearlite partly surrounded by carbide envelopes, but even at the highest carbon content of 0·117%, some carbide still appeared at the grain boundaries, as shown in Fig. 9*c*.

In the water-quenched condition, carbide might be expected at the higher carbon levels only, but, owing to its fineness and the increasing acicularity of the structure, it was difficult to decide at what carbon level it first appeared. However, there were no grain-boundary films of the type seen in the air-cooled and furnace-cooled alloys. The appearance of the ferrite in the 0·01% C alloy is shown in Fig. 10*a*. Figure 10*b*, showing the 0·044% C alloy under the optical microscope, suggests the presence of fine carbide particles, and these were clearly revealed by the electron microscope, as shown in Fig. 10*c*. The structure of the 0·117% C alloy shown in Fig. 10*d* could be described as ferrite plus sorbite; the sorbitic areas that were resolved with the optical microscope had a tendency to be lamellar, but were mainly granular in appearance. The decreasing transition temperatures obtained by water-quenching alloys containing up to 0·044% of carbon are attributed to carbon in solution in the ferrite, but the fast cooling used to retain the carbon in solution also decreased the grain size with increasing carbon content.

Grain-boundary carbide has long been stated to cause brittleness in irons or steels of low carbon content, but it has generally been assumed that failure occurred at the grain boundaries. In this work, although fracture occasionally occurred along a carbide film, in general it was almost entirely cleavage. It thus becomes necessary to explain why the appearance of carbide in the microstructure, in the form described for the furnace-cooled and air-cooled conditions, causes increased brittleness along cleavage planes. Microscopic examination of plated brittle Charpy and tensile test pieces of the alloys as furnace-cooled or air-cooled showed that extensive cracking had occurred in some of the carbide films situated at the grain boundaries or enveloping pearlite areas, as shown for the 0·044% C alloy in Fig. 11*a*. It was noted that cracking of the carbide films was more extensive in regions of a Charpy specimen that had been deformed substantially. It thus appears that deformation of the ferrite may be necessary to cause cracking of the carbide, but the experimental evidence in this direction is not sufficient to warrant a firm conclusion. Whether the carbide could crack when the stress on the ferrite–carbide aggregate is entirely elastic depends on the relative elastic properties of the ferrite and carbide, and on the shape, size, and distribution of the carbide in the ferrite. Photographs of cracked carbide in tensile test pieces have been published by Hanemann and Schrader.[6]

It seems that the cracks produced in the carbide resulted in the development of triaxial stresses in their immediate neighbourhood which could be effective in promoting failure of the ferrite by cleavage. Some of the microscopic evidence confirming this is given here. Figure 11*b* shows a cleavage crack starting in carbide and proceeding into a grain of ferrite in a specimen of the 0·044% C alloy furnace-cooled from 950° C. Figure 11*c* shows in the same specimen a cleavage crack proceeding from a carbide film through the enclosed pearlite into a grain of ferrite. Bruckner[7] has found cracks in carbide films and in the carbide lamellæ of pearlite in mild steel, and has suggested that they are responsible for starting the main cleavage fracture of a specimen. He has also shown cracks in carbide particles in a spheroidized steel, but his photographic evidence that cleavage of the ferrite proceeded from these carbide particles was not convincing. Zednik and Kadeřávek[8] have presented considerable evidence that fracture in a eutectoid carbon steel proceeds parallel with carbide lamellæ in pearlite. The present authors found many more examples of cracks across carbide areas, as in Figs. 11*b* and *c*, than of cracks along the junction between carbide and ferrite, as shown in Fig. 11*d*, so that the former mechanism of the initiation of cracks appears to be more important than the latter at these carbon levels.

A large number of cracks in carbide films were seen in fully ductile specimens, but the condition of the ferrite was such that they did not spread, but opened

out laterally until the ferrite flowed in from their ends around the carbide between the cracks. The deformation markings at the ends of the cracks in the carbide of a semi-tough specimen (Fig. 11*e*) were presumably the result of unusual stress conditions existing at the ends of the cracks.

The shape of the impact-value/temperature curves for the different heat-treatments can be explained on the basis of the above discussion. The impact-value/temperature curves for the 0·117% C alloy are shown in Fig. 3. The curve for the material water-quenched from 950° C. showed a sharp transition from a tough to a brittle fracture, and in this case the microstructure consisted of ferrite containing carbon in solution and some small rounded carbide particles (ferrite + sorbite), as shown in Fig. 10*d*. For the air-cooled and furnace-cooled conditions, whereas the change from the fully tough to the semi-brittle failure was sharp, the subsequent change to the fully brittle behaviour on further lowering the temperature of test was gradual. The material in both these conditions had carbide films present at the grain boundaries and around areas of pearlite (*see* Figs. 8*c* and 9*c*). Starting at the brittle end of the impact-value/temperature curve and raising the temperature of test, the ferrite becomes ductile under the triaxial stress conditions obtaining under the notch, the temperature at which this occurs depending on the amount of carbon held in solution in the ferrite. Whether or not the test piece is fully ductile depends on whether there is an interfering effect due to the carbide. If the carbide is present as fine globules, it presumably interferes little with the deformation of the ferrite, and the temperature at which the test piece as a whole becomes fully ductile is substantially that at which the ferrite becomes ductile. However, when carbide films are present, a large number of small cracks appear in the carbide as soon as the test piece is deformed to a small extent. The triaxiality of the stress concentrated at the ends of these micro-cracks probably varies, there being a large number of cracks with a relatively low triaxiality ratio and a small number with a high triaxiality ratio. Owing to the small size of the micro-cracks, their effect would be expected to be very localized, at least initially. The stress conditions in the test piece are thus much less uniform than they were before the micro-cracks formed; the triaxial stress field due to the notch is 'peppered' by peaks of varying magnitude caused by the micro-cracks. The sloping impact-value/temperature curve is considered to result from the progressive ability of the ferrite to shear in the vicinity of the triaxiality ratio peaks. As the temperature is raised, the less severe peaks cease to be effective in propagating a brittle crack, and the test piece becomes fully ductile when the critical shear stress is reached before the cleavage strength in the regions of the test piece with the severest triaxiality ratio peaks. In a Charpy test piece with a mixed ductile–brittle fracture, the ductile region is around the sides of the test piece. The increase in proportion of the fracture that is ductile as the temperature of test is raised arises from the ductile–brittle boundary moving inwards, the last region to behave in a brittle manner being just inside the notch, where the triaxiality of stress would be expected to be largest.

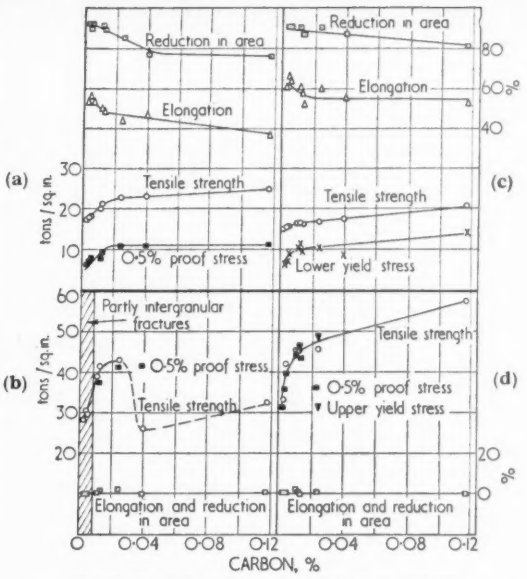



**Fig. 4—Tensile properties of iron–carbon alloys at (*a*) and (*c*) room temperature and (*b*) and (*d*) −196° C. after different heat-treatments**

In addition to the effect of cracks in carbide in starting cleavage of the ferrite, it is possible that under certain circumstances the carbide also acts as a barrier to the progress of a cleavage crack in the ferrite. Whereas this second effect is not considered to be important in the alloys dealt with here, it is possibly significant in other materials.

The impact-value/temperature curves for the double heat-treatments at 950° and 700° C. for the 0·117% C alloy in Fig. 3 are discussed later.

## PROPERTIES OF IRON–CARBON ALLOYS HEAT-TREATED AT 950° AND 700° C.

Double heat-treatments at 950° and 700° C. were carried out to study further the effects of carbon in solution in the ferrite and of carbon present as carbide films on the yield (or proof) stress and the transition temperature.

### Furnace-Cooled 950° C., Water-Quenched 700° C.

Heating to 700° C. after furnace-cooling from 950° C. would cause about 0·015% of carbon to be taken into solution in the ferrite, and this would be retained in solution on water-quenching. Alloys containing carbon up to this level would be expected to behave similarly to those water-quenched from 950° C. Alloys with higher carbon contents than this would be expected to have the effect of the carbide films remaining at 700° C. superimposed on a ferrite having 0·015% of dissolved carbon.

The tensile properties at room temperature of the alloys furnace-cooled from 950° C. and water-quenched from 700° C. are given in Fig. 4*a*. No yield points were obtained in any of the alloys in this condition. The 0·5% proof stress increased to between 11 and

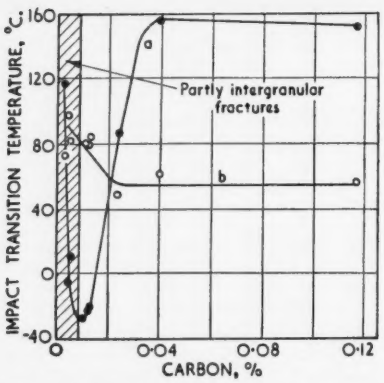



**Fig. 5—Charpy impact transition temperatures of iron–carbon alloys (*a*) furnace-cooled 950° C. and water-quenched 700° C., and (*b*) water-quenched 950° C. and furnace-cooled 700° C.**

11½ tons/sq. in. on increasing the carbon content to between 0·012% and 0·024%, but no further increase occurred at higher carbon levels. This value of the proof stress was slightly less than that expected (about 13½ tons/sq. in. from Fig. 1*a*) by water-quenching a 0·015% C alloy from 950° C. There was also a marked rise in the tensile strength up to a carbon level between 0·012% and 0·024%, but thereafter there was only a slight rise. The elongation and reduction in area tended to be lowered more by increasing carbon content at the low-carbon end of the series.

The tensile properties at −196° C. are given in Fig. 4*b*. It was mentioned earlier that the three lowest-carbon alloys (0·0025%, 0·0042%, 0·0053%) gave partly intergranular fractures when tested in the brittle condition after water-quenching from 950° C. The same occurred on water-quenching from 700° C., and these three alloys had low tensile strengths of 28·5–30·2 tons/sq. in. at −196° C. The proof stresses were not reached and the ductility was negligible. All the other alloys broke with cleavage fractures. The alloys in the range 0·01–0·024% of carbon had normal proof stresses and tensile strengths of about 40 tons/sq. in. with a small amount of ductility. The two higher-carbon alloys (0·04% and 0·117%) tested in this condition had low tensile strengths at −196° C. with no proof stresses, elongation, or reduction in area.

The shape of the tensile-strength curve at −196° C. (which, in view of the low reduction-in-area figures, can be considered to be substantially the brittle-fracture stress curve) is the inverse of that of transition temperature in impact shown in Fig. 5*a*. The three lowest-carbon alloys, which had brittle fractures that were partly intergranular, had higher transition temperatures than would otherwise have been expected. The transition temperature of the lowest-carbon alloy (0·0025%) was particularly high at 118° C. The other alloys gave brittle fractures that were of the cleavage type. The alloys that had all the carbon in solution as a result of quenching from 700° C. (0·0096–0·013%) had low transition temperatures of −21° to −27° C., which were the same as those obtained by water-quenching the alloys from 950° C. (−17° to −27° C.); the impact-value/temperature curves showed a sharp transition from tough to brittle fracture. For carbon contents higher than this, carbide appeared in the microstructure, first along grain boundaries in the 0·024% C alloy, and then also as pearlite surrounded by carbide envelopes in the 0·04% and 0·117% C alloys. In the range 0·013–0·04% of carbon, the impact transition temperature rose sharply to between 150° and 160° C., and remained at this level for the 0·117% C alloy. These results were reflected in the shape of the impact-value/temperature curves, the transition from brittle to tough fractures occurring over a wider temperature range as the transition temperature was raised. That is, at 0·024% of carbon the impact-value/temperature curve rose gradually from the brittle to the semi-tough condition, and there was then a sharp rise to the fully tough condition. For the 0·04% and 0·117% C alloys, which are at the top of the transition-temperature/carbon-content curve, the transition from brittle to fully tough fracture was more gradual and remained so over the whole temperature range, the impact-value/temperature curve not being sharp at any stage, as shown in Fig. 3. These were the only two cases encountered in which the brittle-to-tough transition was gradual over the whole of its range, and, as mentioned, they had the highest transition temperatures. This behaviour is consistent with the view that the high transition temperatures are due to the carbide. It is not clear, however, why the highest transition temperature of nearly 160° C. recorded in this series was about 30° higher than the highest value obtained on furnace-cooling from 950° C. The carbide appeared to be a little coarser after heating at 700° C., and it is possible that such a difference could be responsible for the larger effect of carbon in raising the transition temperature.

#### Water-Quenched 950° C., Furnace-Cooled 700° C.

Heating at 700° C. after water-quenching from 950° C. would result in carbon in excess of about 0·015% being precipitated as carbide globules. Furnace-cooling from 700° C. should then cause the 0·015% of carbon to be precipitated, leaving very little carbon in solution in the ferrite.

The tensile properties at room temperature of the alloys in this condition are shown in Fig. 4*c*. As would be expected, all the alloys showed a yield. There was a marked rise in the yield stress up to the 0·013% C alloy, after which the rise was more gradual. The tensile strength followed a similar course, but the rise up to 0·013% of carbon was less marked than that for the yield stress. The elongation fell slightly up to 0·013% of carbon, after which it remained substantially constant. The effect of increasing carbon content on reduction in area was to cause a uniform but small lowering.

It is of interest to compare these properties with those for the alloys when furnace-cooled from 950° C. The rise in yield stress up to 0·013% of carbon was significantly larger when the alloys had been furnace-cooled from 700° C. than when furnace-cooled from 950° C. This difference is presumably an effect of the

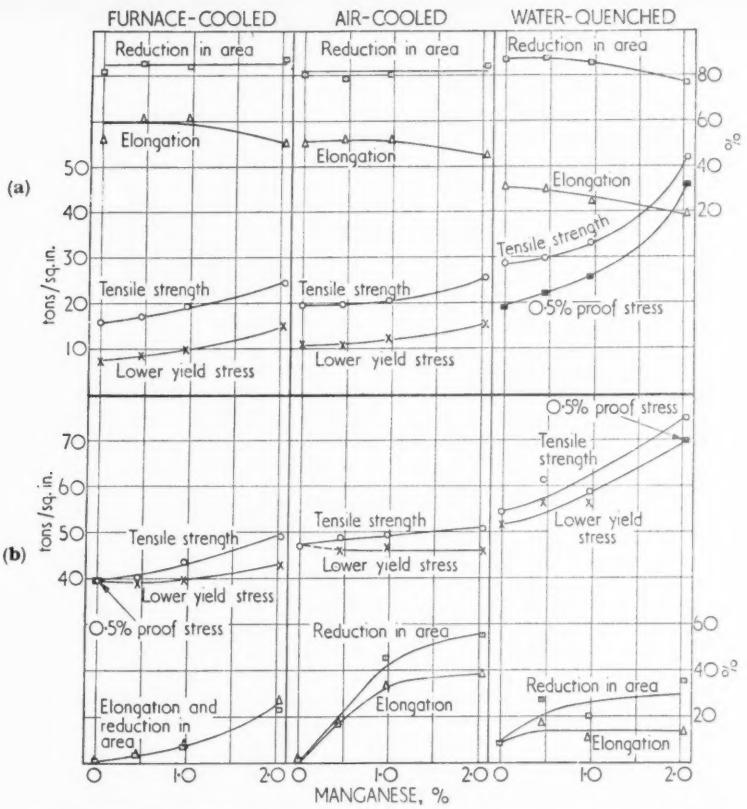



**Fig. 6—Tensile properties at (*a*) room temperature and (*b*) −196° C. of Fe–0·05% C–Mn alloys cooled at different rates from 950° C.**

more rapid grain refinement with increasing carbon content resulting from the double treatment of water-quenching from 950° C. and furnace-cooling from 700° C. compared with that resulting from the single treatment of furnace-cooling from 950° C. For carbon contents above 0·013%, the more rapid rise in yield stress and tensile strength for the alloys given the double treatment could be due to both difference in grain size and condition of the carbide.

The tensile properties at −196° C. are shown in Fig. 4*d*. Increasing the carbon content to 0·013% resulted in a marked rise in tensile strength, but for higher carbon contents the rise was more gradual. The fractures occurred entirely by cleavage, and, since the elongation and reduction in area were in no case more than 2%, the cleavage strengths were practically equal to the tensile strengths. It is noteworthy that furnace-cooling from 700° C. has removed the tendency to intergranular brittleness produced in the three lowest-carbon alloys by the previous water-quenching from 950° C.

The transition temperatures in the Charpy impact test are shown in Fig. 5*b*. At carbon levels above the solubility limit at 700° C., the transition temperature was substantially constant in the range 49–61° C. The carbide in these alloys consisted largely of globules, the carbide in solution at 700° C. being deposited to a large extent on the existing globules during furnace-cooling. The alloys with carbon contents less than the solubility limit at 700° C. had rather higher transition temperatures, presumably because the carbide in these alloys was deposited entirely as grain-boundary films on slow cooling from 700° C. The embrittling effect of the carbide films would be expected to increase with carbon content up to the 0·013% C alloy, but this is a secondary effect superimposed on the ferrite, the transition temperature of which is governed by its yield stress and cleavage strength. The yield stress at room temperature rose appreciably in this carbon range, and presumably this would also occur at the higher temperature of about 80° C. relevant in the impact test. The cleavage strength, as determined at −196° C., also rose considerably up to 0·013% of carbon, so that the net effect is not easy to predict.

## PROPERTIES OF IRON–CARBON–MANGANESE ALLOYS

The tensile properties at room temperature of the iron–0·05% carbon–manganese alloys after furnace-cooling, air-cooling, and water-quenching from 950° C. are shown in Fig. 6*a*. The alloys showed sharp yield points in the furnace-cooled and air-cooled conditions, but not in the water-quenched condition. Addition

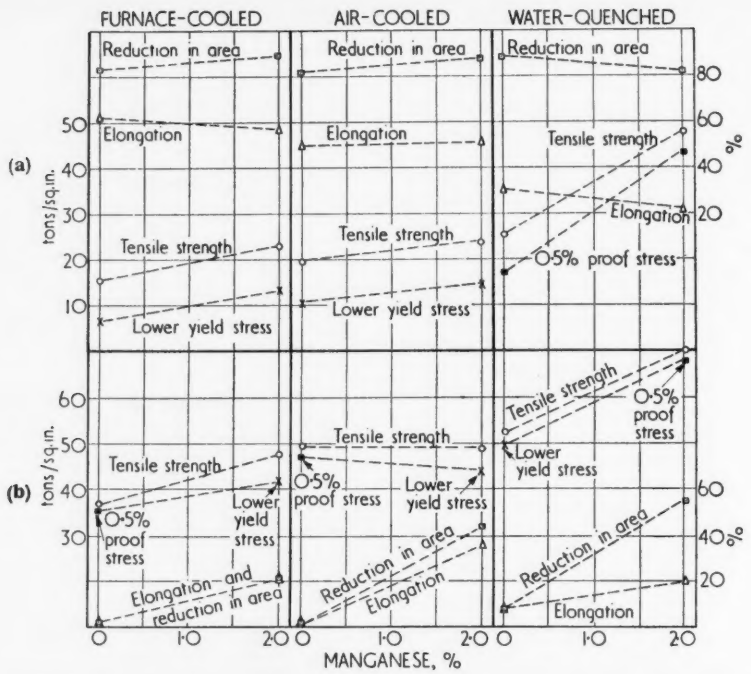



**Fig. 7—Tensile properties at (*a*) room temperature and (*b*) −196° C. of Fe–0·03% C–Mn alloys cooled at different rates from 950° C.**

of manganese up to 2% resulted in an increase in yield (or proof) stress and tensile strength, the effect being particularly marked after water-quenching. In the furnace-cooled and air-cooled conditions, the elongation was little affected by manganese up to 1%, but there was some reduction at 2%. After water-quenching, the addition of manganese progressively lowered the elongation. The reduction in area tended to be decreased a little by increasing manganese content in the water-quenched alloys, but there was no effect with the slower rates of cooling. The effect of increasing the rate of cooling was to raise the yield (or proof) stress and tensile strength, and to decrease the elongation.

The effect of adding 2% of manganese to an iron–0·03% carbon alloy on the tensile properties at room temperature, shown in Fig. 7*a*, confirmed the effects obtained at the 0·05% carbon level.

The tensile properties at −196° C. of the Fe–0·05% C–Mn alloys for the three rates of cooling from 950° C. are shown in Fig. 6*b*. Yield points were obtained in the furnace-cooled and air-cooled conditions, except in the completely brittle alloy containing no manganese. In the water-quenched condition, no yield point was obtained in the Fe–0·05% C–2% Mn alloy. The effect of increasing the manganese content on the yield stress and tensile strength in the furnace-cooled and air-cooled conditions was not very marked, but it was large in the water-quenched condition. In general, the elongation and reduction in area rose with increasing manganese content, indicating that the transition temperature in tension was lowered. Increasing the rate of cooling resulted in a rise in the yield (or proof) stress and tensile strength. The elongation and reduction in area were higher after air-cooling than after furnace-cooling, but further increase in rate of cooling lowered the ductility at 1% and 2% of manganese, presumably owing to the distortion of the α-lattice at the higher manganese levels.

The effect of adding 2% of manganese at the 0·03% C level on the tensile properties at −196° C. is shown in Fig. 7*b*. The results are similar to those for the 0·05% carbon–2% manganese alloy discussed above, except that in the water-quenched condition the elongation and reduction in area were higher. The distortion of the lattice on water-quenching a 2% Mn alloy would be expected to be greater with higher carbon contents, thus giving a lower ductility at −196° C. This is consistent with the results of the Charpy impact tests discussed below. There is evidence that a distorted structure ($\alpha_2$) forms in a carbon-free 3% Mn alloy on air-cooling from 950° C.,[1] so that it appears reasonable to suppose that increasing the rate of cooling and introducing carbon would produce lattice distortion in a 2% Mn alloy ; it would also be expected that the distortion would be found first at the higher 0·05% C level.

The fractures of all the tensile specimens of the Fe–C–Mn alloys tested at −196° C. occurred entirely by cleavage, even though reductions in area of up to 55% were obtained and the test pieces with reductions in area above about 20% had necked.

The impact transition temperatures of the Fe–0·05% C–Mn alloys for the three rates of cooling from 950° C. are shown in Fig. 16*a*. Increasing the

Fig. 8—Iron–carbon alloys normalized at 950° C. ; carbon contents (*a*) 0·01% ; (*b*) 0·024% ; (*c*) 0·117%  (*a*) × 150 ; (*b*) and (*c*) × 1500

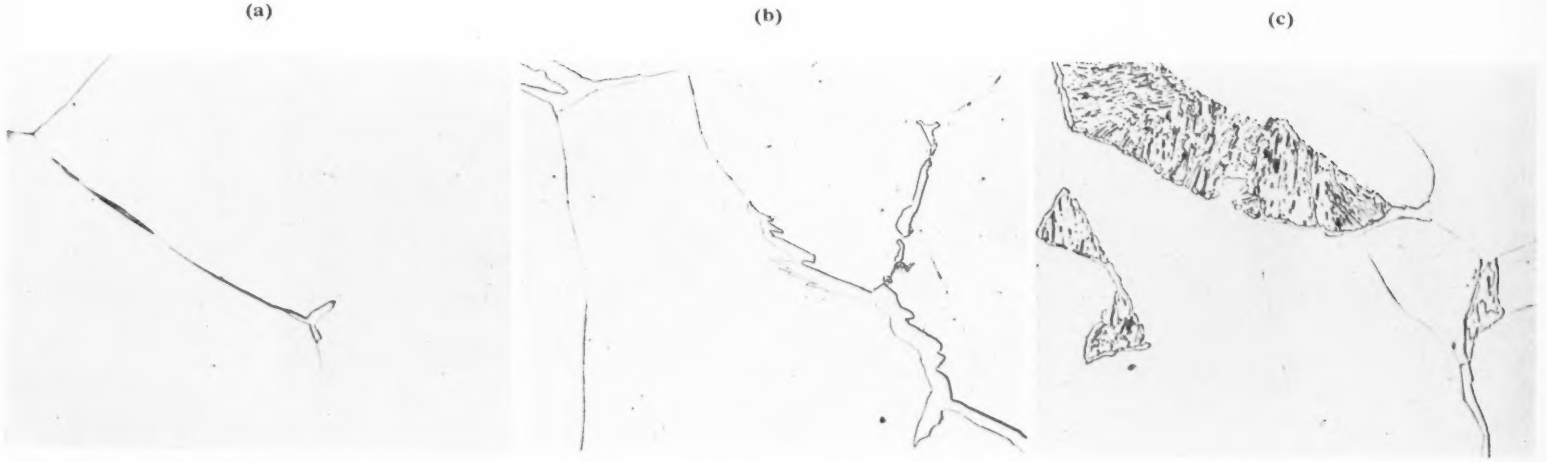



Fig. 9—Iron–carbon alloys furnace-cooled from 950° C. ; carbon contents (*a*) 0·0025% ; (*b*) 0·028% ; (*c*) 0·117%  (*a*) and (*b*) × 1500 ; (*c*) × 500

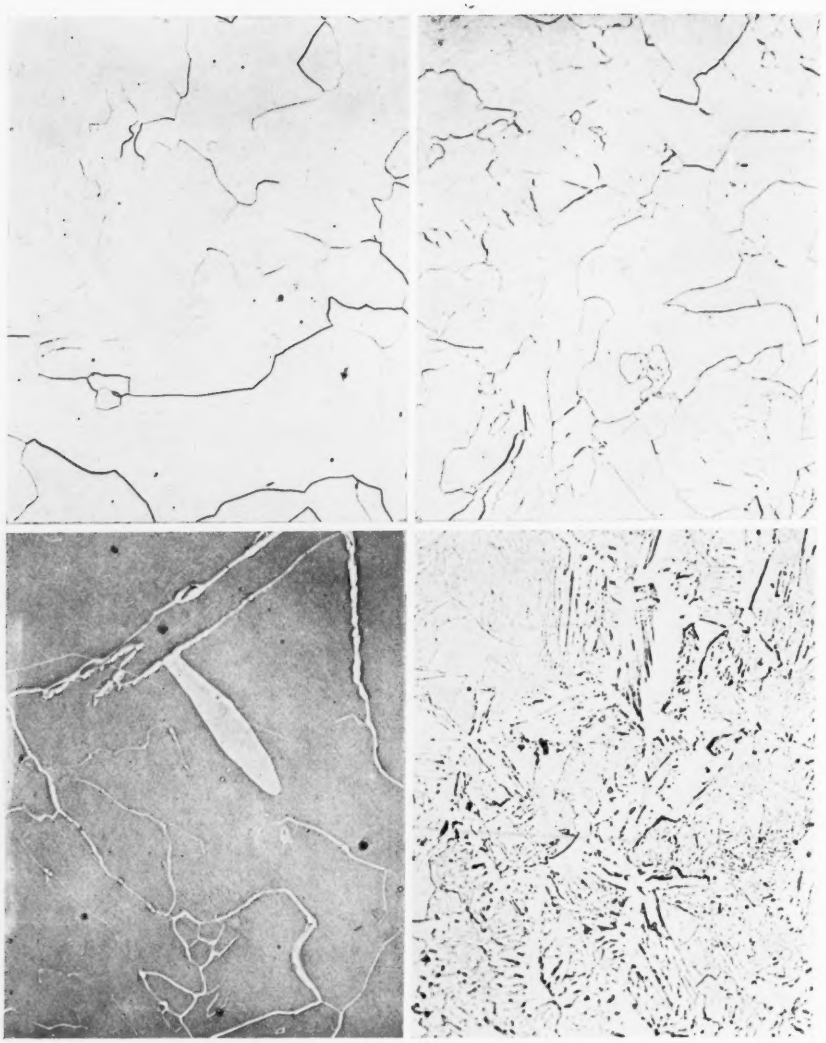



**Fig. 10—Iron–carbon alloys water-quenched from 950° C. ; carbon contents (*a*) 0·01% ; (*b*) and (*c*) 0·044% ; (*d*) 0·117%. Electron micrograph (*c*) shows some rounded carbon particles ; the continuous white lines are grain or sub-grain boundaries (*a*) × 150 ; (*b*) and (*d*) × 500 ; (*c*) × 2200**

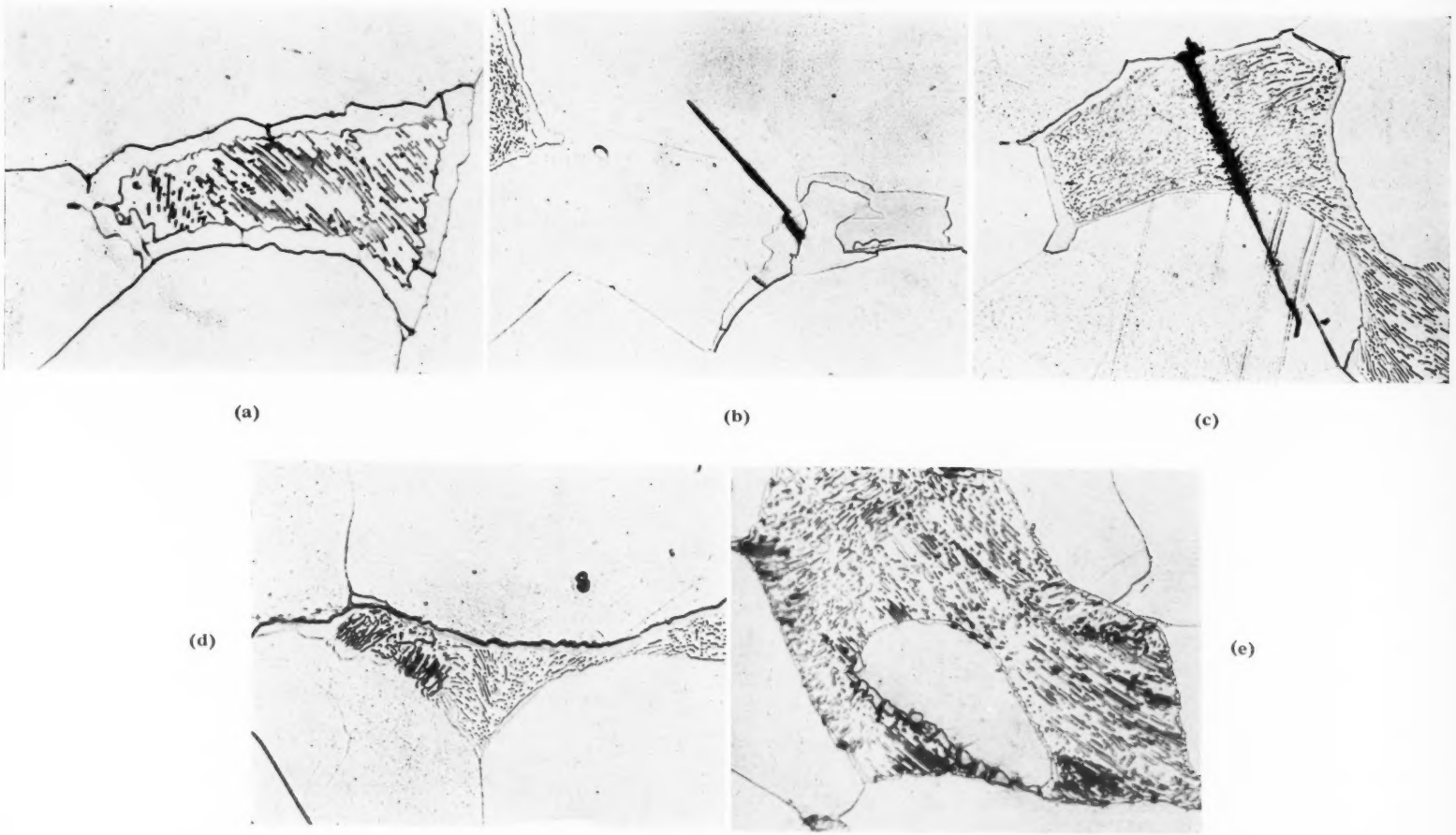



Fig. 11—Iron–carbon alloys furnace-cooled from 950° C.: (*a*)–(*d*) Brittle specimens of 0·044% C alloy; (*e*) semi-tough specimen of 0·117% C alloy (*a*) × 1500; (*b*)–(*e*) × 500

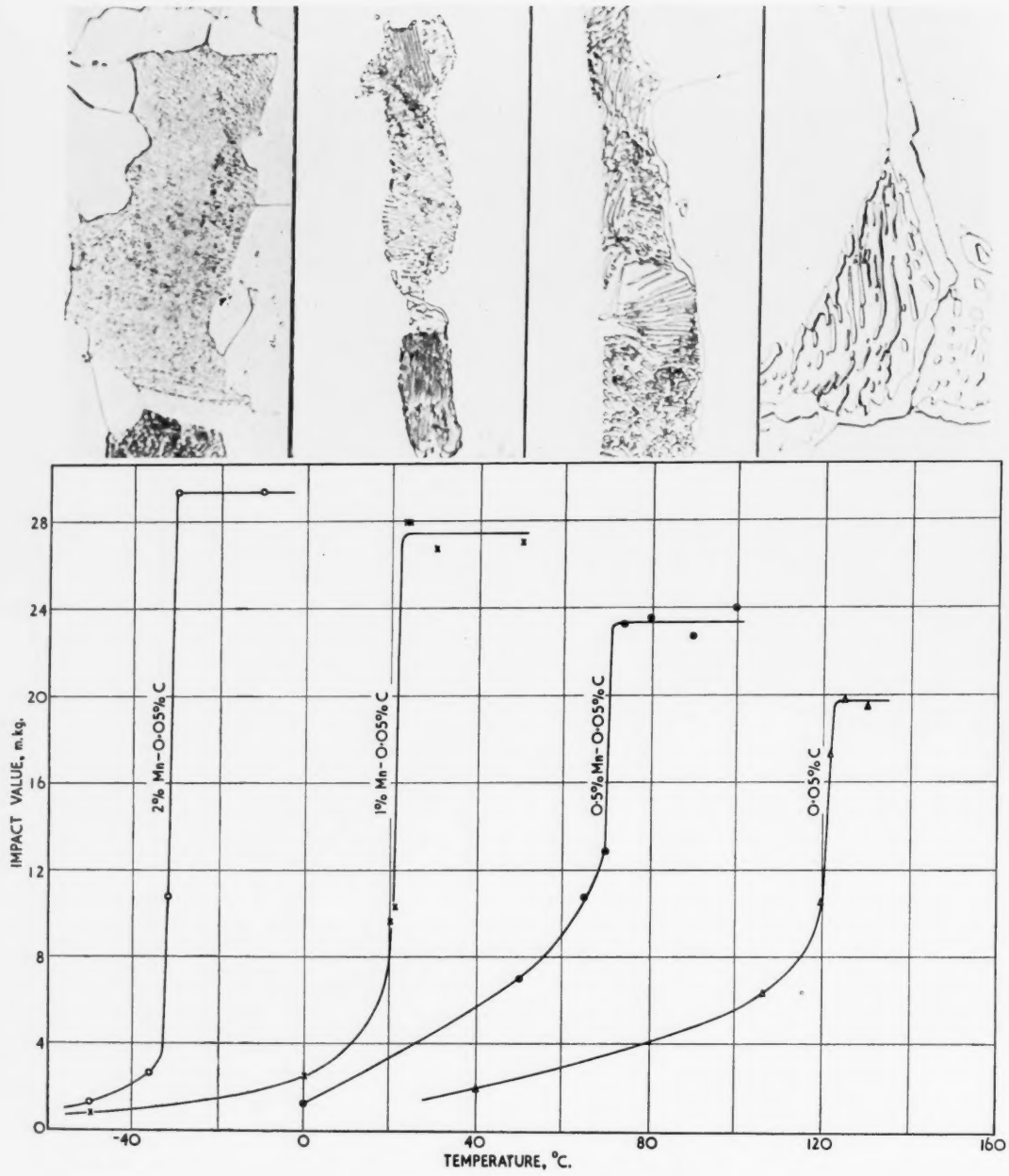



**Fig. 12—Impact values at various temperatures of iron–0·05% carbon alloys with manganese additions up to 2% furnace-cooled from 950° C., showing microstructures (× 1500)**

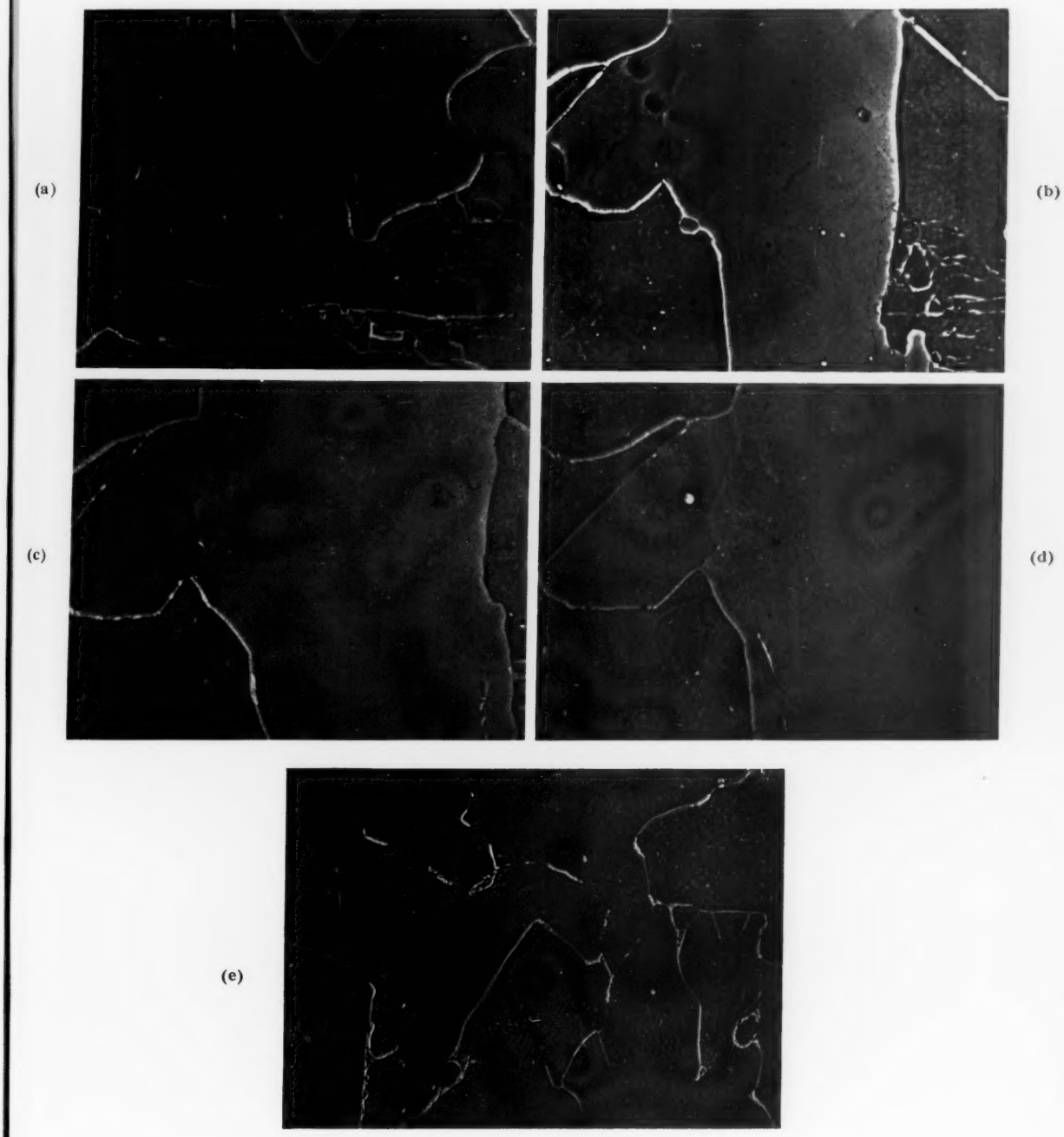
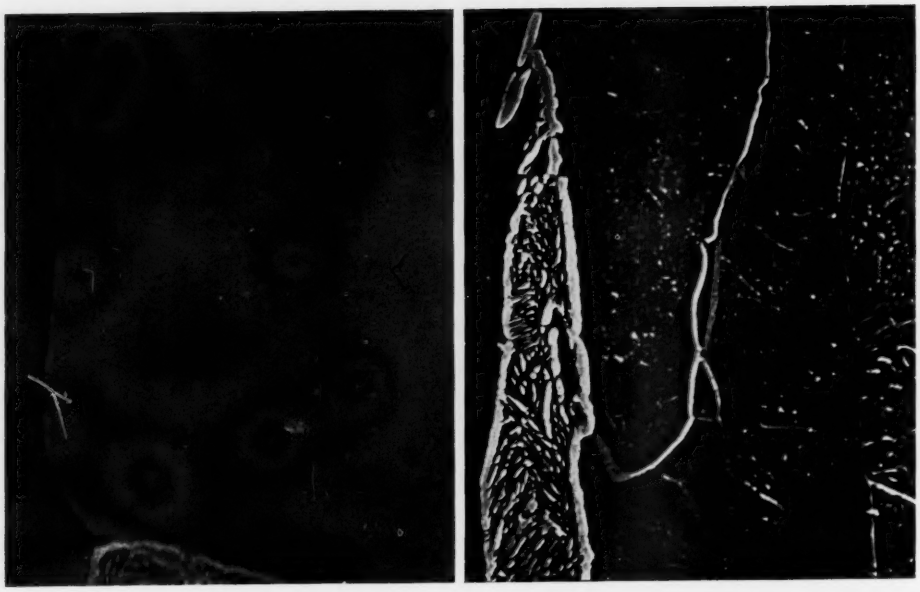



**Fig. 13—Electron micrograph of 0·044% C alloy water-quenched from 950° C. and aged for (*a*) 2 days ; (*b*) 6 days ; (*c*) 36 days ; (*d*) 71 days ; and (*e*) several months** × 2500

(a)



(b)

Fig. 14—Electron micrographs of 0·044% C alloy ; (*a*) 5 hr. after air-cooling from 950° C., and (*b*) air-cooled from 950° C. and aged about 18 months at room temperature; polished by hand × 2500

Fig. 15—Electron micrograph of 0·05% C–2% Mn alloy air-cooled from 950° C. and aged about 18 months at room temperature ; polished by hand × 2500

manganese content up to 2% progressively lowered the transition temperature from 119° to −31° C. for the furnace-cooled alloys, and from 74° to −65° C. for the air-cooled alloys. The transition temperatures of the water-quenched alloys were also lowered from −57° to −73° C. on adding manganese up to 1%, but a further increase in manganese content to 2% caused the transition temperature to rise to −10° C. This rise agrees with the tensile test results at −196° C., and was presumably due to the formation of a distorted lattice. Apart from the 0·05% C–2% Mn alloy when water-quenched, the effect of increasing the rate of cooling was to lower the transition temperature. The benefit derived from water-quenching was very large in the manganese-free alloy but became less with increasing manganese up to 1%, although it was still large at 1%.

The effect of adding 2% of manganese on the impact transition temperature of the 0·03% C alloy is shown for the three rates of cooling from 950° C. in Fig. 16*b*. The results follow closely those for the 0·05% C alloys. The transition temperature of the manganese-free 0·03% C alloy was a little higher than that of the corresponding 0·05% C alloy for each rate of cooling. The transition temperature of the 0·03% C–2% Mn alloy was also slightly higher than that of the 0·05% C–2% Mn alloy in the furnace-cooled and air-cooled conditions. Water-quenching raised the transition temperature of the 0·03% C–2% Mn alloy, but not as much as for the 0·05% C–2% Mn alloy. This agrees with the tensile results at −196° C. for both these alloys and, as mentioned earlier, was probably due to the formation of a distorted lattice, which would be expected to be more pronounced for the higher-carbon alloy.

In all the Fe–C–Mn alloys, the fractures of the impact test pieces that broke in a brittle manner were entirely of the cleavage type. The connection between cracking of carbide films at the ferrite grain boundaries or enveloping areas of pearlite and the shape of the impact-value/temperature curve has already been discussed for the Fe–C alloys. Progressive additions of manganese reduced the tendency for the carbide to appear as films; at 1% of manganese there were only occasional examples and at 2% of manganese no such films were detected. This is shown in Fig. 12, together with the effect on the shape of the impact-value/temperature curves at the 0·05% C level for the alloys furnace-cooled from 950° C. The spread of the transition at the lower end of each curve decreased as the manganese content was increased, *i.e.*, as the tendency to form carbide films was reduced. The impact value in the fully tough condition also increased with manganese content, until at 1–2% of manganese the value usually obtained for irons and iron alloys that give a sharp change from tough to brittle fracture was reached. The character of the pearlite also changed as the manganese content was increased in that it became more granular, as is usually found in manganese steels ; this may have a bearing on the ease with which cleavage fractures develop. Similar remarks apply to the shape of the impact-value/temperature curves that have already been published[1] for the alloys in the normalized condition. No carbide films formed

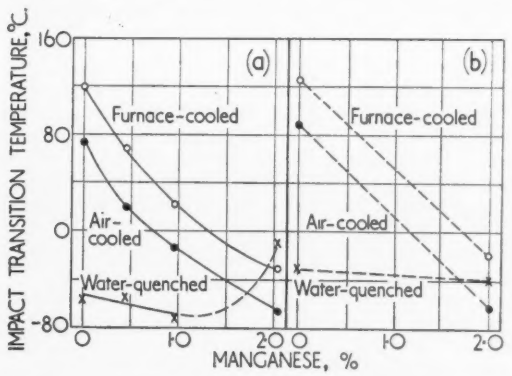



**Fig. 16—Charpy impact transition temperatures of (*a*) Fe–0·05% C–Mn and (*b*) Fe–0·03% C–Mn alloys cooled at different rates from 950° C.**

on water-quenching from 950° C., and all the alloys exhibited a sharp transition from tough to brittle fracture.

## AGEING AT ROOM TEMPERATURE

The iron–carbon alloys were not stable at room temperature after water-quenching from 950° C., in that the properties changed with time. The quench ageing of these alloys was not investigated in detail, but the magnitude of the effect was ascertained in two cases. The 0·028% and 0·044% C alloys gave transition temperatures in impact of −31° and −57° C. respectively as water-quenched from 950° C., but ageing for eight weeks at room temperature raised the transition temperature by over 50° C. in each case to 22° and 1° C. respectively. Individual impact tests at temperatures above the original transition temperature confirmed that ageing also occurred to about this extent in some of the other Fe–C alloys. Tensile tests on specimens aged at room temperature did not, on the whole, show significant effects on the yield point; *e.g.*, the 0·044% C alloy gave about the same proof stress and tensile strength after 11 weeks' ageing at room temperature as in the freshly water-quenched condition, although a yield was obtained after ageing but not as water-quenched. It thus appears that the effect in impact is more prominent than that in tension after these ageing periods. The trends with time of ageing were not investigated; maximum ageing would, however, be expected after about 12 weeks at room temperature.

The practice was adopted in the Charpy impact testing, at temperatures other than room temperature, of giving the specimens ¼ hr. after immersion in the hot or cold bath before removal for testing. Substantial ageing could therefore occur during test in the materials tested well above room temperature. This applies mainly to the air-cooled alloys, since most of the water-quenched alloys had low transition temperatures. The extent of the ageing in the air-cooled alloys is believed to be small, however, because of the relatively small amount of carbon held in solution. No ageing would be expected in the alloys when furnace-cooled.

The ageing characteristics of the Fe–C–Mn alloys were different from those of the Fe–C alloys. Although the effect of manganese on ageing was not investigated in detail, individual impact tests showed that the 0·05% C–0·5% Mn alloy had its transition temperature raised more than 15° C. on ageing for 20 weeks at room temperature, but that the 0·05% C–1% Mn and 0·03% C–2% Mn alloys were still tough at a temperature 15° C. above the transition temperature in the water-quenched condition.

The microstructural changes that occur during ageing are discussed in Appendix II.

A rise in transition temperature in the Charpy impact test at a constant yield stress implies that the cleavage strength at the transition temperature is lowered by ageing. This could arise from two causes: either the cleavage strength of the ferrite is reduced because of the decrease in the amount of carbon in solution, or the effect is due to the carbide that is precipitated, or both. It has already been seen that the increase in cleavage strength that occurs as a result of raising the carbon content of these alloys may be due, at least in part, to the accompanying decrease in grain size. Ageing, however, involves the deposition of carbon from solution without a change in grain size, so that, although it is not possible to state definitely that decrease in cleavage strength on ageing is due to the decrease in the amount of carbon in solution, it appears likely that this is at least partly so. There may also be a direct effect of the precipitated carbide on the cleavage strength.

## DISCUSSION

Under any given conditions of stress, it should be possible to explain the changes in the temperature of transition from ductile to brittle behaviour, as affected by variation in composition or heat-treatment, if the effective yield stress and brittle-fracture strength (or cleavage strength, if brittle fracture occurs entirely by cleavage) are known. Attempts to explain changes in transition temperature in impact on the basis of the yield stress and cleavage strength should, strictly speaking, make use of these values in the range over which the transition temperature alters. A method of determining the value of the cleavage strength at such relatively high temperatures has not yet been developed, however, and one has to rely on the values determined at a temperature at which the material is completely brittle in plain tension, *e.g.*, at −196° C. A further complication arises from the difference in rate of straining in the tensile and impact tests; the effect of rate of straining may be dependent on the heat-treatment to which the material is subjected.

Correlation of the tensile and impact test results for the Fe–C alloys is thus hardly possible, particularly in relation to certain features. For instance, in the air-cooled alloys, there was a sharp rise in impact transition temperature between 0·01% and 0·03% of carbon, but in tension there was only a small rise in yield stress and a somewhat larger rise in cleavage strength.

The tensile and impact properties of the Fe–C–Mn alloys are easier to correlate because the changes are mostly gradual and progressive. The generally increasing ductility at −196° C. with manganese content indicates that the transition from ductile to brittle fracture in tension was lowered. Since the yield or proof stress at this temperature either was approximately constant or rose with manganese content for the three rates of cooling from 950° C., the cleavage strength must have been raised.

In a previous paper[1], in which tensile test results were reported for −73° C. as well as for room temperature and −196° C. for the Fe–C–Mn alloys in the condition air-cooled from 950° C., it was argued that, since the yield stress increased with manganese content over the temperature range in which the impact transition temperature was lowered, the cleavage strength must also have been raised by manganese over the same temperature range.

For the furnace-cooled condition, yield-stress values are available at room temperature, and they increase with manganese content. The impact transition temperature was lowered from about 120° to −30° C. by manganese additions up to 2%, and since it is likely that the trend of the yield stress is the same over the whole of this temperature range as it is at room temperature, it can be argued that the cleavage strength in this range was increased by manganese for the furnace-cooled condition also.

The same applies to the water-quenched condition for manganese contents up to 1%. The rise in impact transition temperature in the 0·05% C–2% Mn alloy may be due to the rapid rise in yield stress that occurs on forming $\alpha_2$ (or martensitic type) structure. The above arguments assume that the faster rate of straining in the impact test compared with that in the tensile test has a similar effect on the yield stress, irrespective of manganese content. This is probably true for any one heat-treatment, but a variation in heat-treatment that substantially changes the structure may well alter the strain-rate sensitivity of the yield stress.

A feature of interest in this work is the good combination of tensile and impact properties obtained by water-quenching some of the Fe–C alloys. At about 0·05% of carbon, for example, it is possible to obtain at room temperature a 0·5% proof stress of over 20 tons/sq. in., a tensile strength of about 30 tons/sq. in. with good elongation and reduction in area, and a low transition temperature in impact of about −60° C. This is thought to be due largely to the retention of this amount of carbon in solution in the ferrite, although, as already mentioned, the effect may be due at least partly to the refinement of the grains produced by the same treatment. If the carbon content is raised much above this level, the impact transition temperature starts rising, and eventually a brittle martensitic structure is produced. The electron micrographs described in Appendix II support the view that a significant amount of carbon was retained in solid solution in quenched alloys, and that the precipitation of this carbon during prolonged ageing at room temperature is the cause of the deterioration of properties that occurred with time.

Still better tensile properties at room temperature and lower impact transition temperatures are obtained by adding manganese at the 0·03% or 0·05% C level, provided that the manganese content is below the level at which an $\alpha_2$ or martensitic structure starts to form, at which stage the impact transition tempera-

ture starts to rise. For instance, the 0·05% C–1% Mn alloy water-quenched from 950° C. gave at room temperature a 0·5% proof stress of about 26 tons/sq. in., a tensile strength of 33 tons/sq. in. with good elongation and reduction in area, and a transition temperature in impact of −73° C.

Although the properties of the water-quenched Fe–C alloys are not stable because of quench ageing, which results in a large rise in impact transition temperature, this effect is much less marked in the Fe–C–Mn alloys.

Attention may be drawn to the wide range of fracture stresses exhibited by materials that broke at −196° C. with a brittle fracture. These fracture stresses ranged from about 26 to 64 tons/sq. in., the lowest fracture stresses being found in very low-carbon material that had been water-quenched from either 950° or 700° C., and the highest in material containing 0·05% or more of carbon that had been water-quenched from 950° C., a treatment favourable to the retention of carbon in solid solution. In considering the causes of susceptibility to sudden fracture at notches, the variations of fracture stress are of equal importance with the variations of yield stress. The view sometimes expressed that a raising of the yield point is necessarily accompanied by an increased susceptibility to brittle fracture cannot be accepted.

### Acknowledgments

The work described in this paper was carried out in the Metallurgy Division of the National Physical Laboratory, under the general research programme of the Laboratory and the British Iron and Steel Research Association. It is published by permission of the Director of the Laboratory and with the approval of the Association. The authors acknowledge the assistance of Mr. C. C. Earley with the microscopic examination.

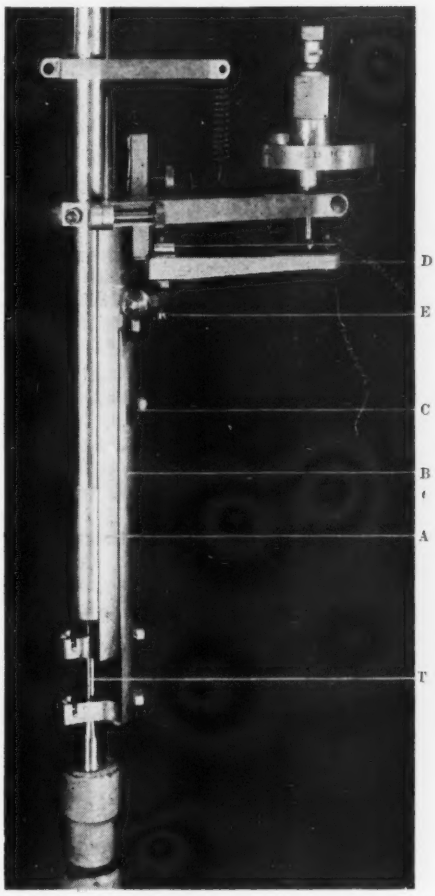



**Fig. 17—View of extensometer** × approx. ⅔

## APPENDIX I

### Extensometer Suitable for Use at Low Temperatures

The extensometer was designed* to fulfil the following conditions:

(1) It should be sensitive enough to measure the usual proof stresses on a 1-in. gauge length
(2) It was required for use at low temperatures while the test piece was immersed in a liquid refrigerant
(3) Since the materials to be tested might be almost completely brittle at low temperatures, it was important that the extensometer should not be damaged if the test piece fractured before the proof stresses were reached.

The extensometer (*see* Fig. 17) consists of two hemicylindrical arms; the inner one *A* is connected at its lower end to the test piece *T*, and the upper end, which carries the measuring device, is guided by the shackle of the testing machine. The weight of the arm and attachments is supported by a spring from an arm on the shackle. The outer arm *B* is also connected to the test piece at its lower end, the upper end being guided by two rollers bearing on the inner arm; contact is maintained by means of a leaf spring *C*.

The measuring device consists of a micrometer screw gauge, which is attached to the inner arm and can be adjusted to make an electrical contact on the arm *D*, which is also attached to the inner arm through a cross spring strip suspension. This arm is supported in a convenient position by a pivot on a plane at the top of screw *E* and in line with the cross strips. Both arms *A* and *B* are fixed in pop marks at either end of the gauge length of the test piece by point and roller contacts. As the test piece extends, the end of arm *D* remote from the shackle drops, thus separating the electrical contacts, and its movement is measured by screwing down the micrometer screw gauge to remake contact, thereby relighting a lamp, which is in series with the electrical contacts.

Should the test piece break, the outer arm *B* is free to slide away from the rest of the extensometer without damage to either part. The micrometer screw gauge is graduated in 0·0002-in. divisions and the lever magnification is 10 : 1, so that an extension of the test piece of 0·00001 in. is easily measured.

* By Mr. H. V. Pollard, of the Mechanical Engineering Research Organisation.

## APPENDIX II

### Electron Microscope Study of the Microstructural Changes during Ageing

*By C. C. Earley and J. F. Nankivell*

The electron microscope was used to examine the microstructures of some of the alloys dealt with in this paper, with particular reference to the changes occurring on ageing at room temperature, so as to correlate with the corresponding changes in mechanical properties. Except where otherwise stated, the specimens were electrolytically polished and then etched for 10 sec. in 2% nitric acid in alcohol. Similar effects were obtained with hand polishing. In the determination of the effects of ageing, observations were made on the same area (using the technique described by Nankivell[9]) after the successive ageing periods. Since material to a depth of about 10$\mu$ was removed in polishing between observations, the outlines of particular grains vary considerably from one micrograph to the next. Nevertheless, by observing the same grains, *i.e.*, the same orientations of the matrix relative to the surface, a more exact comparison of the effects can be made. Throughout the work Formvar plastic replicas were used.

Figure 13*a*, which shows the structure of the 0·044% C alloy 2 days after water-quenching from 950° C., reveals occasional small carbide particles, mostly at the grain and sub-grain boundaries. The white boundaries in the photograph indicate that the particles were raised above the general level of the grains. An important feature is that the ferrite grains were clear and showed no background structure. The microstructure 1 hr. after quenching was similar. A general mottling of the ferrite became evident after ageing for 6 days, as shown in Fig. 13*b*. One grain in this figure showed little if any evidence of mottling, but it could be made to appear after longer etching times. After 36 days, the mottling assumed more the character of a background containing fine particles, as shown in Fig. 13*c*, whereas after 71 days (*see* Fig. 13*d*) the particles appeared to be fairly distinct. The effect of over-ageing for several months is shown in Fig. 13*e*. The proof that these fine white areas were due to carbide has already been given by Tsou, Nutting, and Menter.[10] The change in transition temperature in impact that accompanied the precipitation of carbide during ageing is discussed in the paper.

When the same alloy was furnace-cooled from 950° C., the ferrite grains showed no evidence of fine carbide particles of the above type, the rate of cooling being sufficiently slow for the carbide deposited from solution to appear in a relatively large form. Clear ferrite grains were also produced when the alloy was air-cooled from 950° C., as shown in Fig. 14*a*, but standing at room temperature for 18 months resulted in the appearance of fine white areas within the grains, as shown in Fig. 14*b*. This is additional proof to that given in the paper (where it is stated that no carbide is visible in specimens containing up to about 0·01% C when air-cooled from 950° C.) that some carbon is retained in solution by this heat-treatment. The white areas shown in Fig. 14*b* (normalized and aged for about 18 months at room temperature) are generally larger than those in Fig. 13*e* (water-quenched and aged for several months at room temperature); this may be due to a greater degree of supersaturation in the water-quenched specimen resulting in more widespread nucleation than in the normalized material, or possibly merely to the longer ageing time for the normalized material.

It has been stated in the paper that the Fe–C–Mn alloys aged at room temperature to a much smaller extent than the Fe–C alloys. Some evidence for this was also obtained from electron microscope examination of the alloys. At the 0·05% C level, white areas were present in the manganese-free alloy after ageing the normalized material for 18 months at room temperature (*see* Fig. 14*b*). Some white areas were also seen at ½% of manganese after a similar treatment. It was doubtful whether any white areas were present at 1% of manganese, but none was found in the 2% Mn alloy, as shown in Fig. 15. Since precipitation should be easier to detect in water-quenched material, the Fe–0·05% C–2% Mn alloy was examined after water-quenching and ageing for 8 months at room temperature, but the structure was so obscured by the presence of the acicular $\alpha_2$ (distorted ferrite) structure that it was difficult to decide whether white areas were present. However, if precipitation of carbide had occurred on ageing, it would be possible to state that its extent was much less than in the corresponding manganese-free alloy. Electron microscope examination thus confirmed the results of the few mechanical tests carried out to determine the effect of manganese on the ageing of the Fe–C alloys.

Mr. Earley is at the National Physical Laboratory and Mr. Nankivell is at the Defence Research Laboratory, Victoria, Australia.

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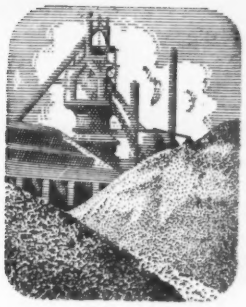


# Studies on the Melilite Solid Solutions

*By R. W. Nurse, M.Sc., F.Inst.P., and H. G. Midgley, M.Sc., Ph.D., F.G.S.*

SYNOPSIS

Melilite is the major constituent of crystalline blast-furnace slag; the melilite series of minerals is also found in cement clinkers and in some natural rocks. From a consideration of the structure and chemical composition of melilites, the following general formula may be postulated: $(CaNaK)_2$ (Mg, Fe″Fe‴Al) $(SiAl)_2O_7$. This suggests the following end members: åkermanite, $Ca_2MgSi_2O_7$; gehlenite, $Ca_2Al_2SiO_7$; iron-åkermanite. $Ca_2Fe''Si_2O_7$; iron-gehlenite, $Ca_2Fe'''SiAlO_7$; sodium-melilite, $NaCaAlSi_2O_7$; potassium-melilite, $KCaAlSi_2O_7$. Of these, the first five have been prepared artificially from pure oxides and the following systems have been investigated: (i) $Ca_2MgSi_2O_7$–$Ca_2Fe'''SiAlO_7$; (ii) $Ca_2Al_2SiO_7$–$Ca_2Fe'''SiAlO_7$; (iii) $NaCaAlSi_2O_7$–$Ca_2MgSi_2O_7$; (iv) $NaCaAlSi_2O_7$–$Ca_2Al_2SiO_7$; (v) $KCaAlSi_2O_7$–$Ca_2Al_2SiO_7$, and (vi) $Ca_2MgSi_2O_7$–$Ca_2Al_2SiO_7$–$Ca_2Fe'''SiAlO_7$.

Phase equilibrium and refractive indices diagrams have been constructed. The results show that these melilites form complete solid solutions with each other. It has also been found experimentally that diopside and calcium orthosilicate enter into solid solution, to a very limited extent, with melilites. 752

## Introduction

THE melilites are tetragonal silicates or alumino-silicates forming an extensive series of solid solutions that cover a wide range of chemical composition. The group was first named by Bellevue;[1] early workers suggested the formula $3CaO.Al_2O_3.SiO_2$ for naturally occurring gehlenite, but Shepherd and Rankin[2] showed, by means of synthetic preparations, that the composition is $2CaO.Al_2O_3.SiO_2$. Later, Ferguson and Buddington[3] delineated the phase diagram for the most important solid-solution series, gehlenite ($2CaO.Al_2O_3.SiO_2$)–åkermanite ($2CaO.MgO.2SiO_2$).

Melilites are of technological importance because they form the major constituent of crystalline blast-furnace slag; they are also found in high-alumina cement, and they may be formed during slag attack on basic refractories. They are found in nature, where they occur in the zone of contact of metamorphosed limestones, and in basic igneous rocks with a high CaO content.

Natural melilites contain appreciable quantities of alkalis and iron, and various workers have suggested solid-solution series to account for this. Berman[4] suggested the general formula: $(Ca + Na)_{20-x}Mg_y Al_3Si_{20-y-z}O_{70}$, where $x = 0$–3, $y = 0$–10 and $z = 0$–20.

Warren[5] determined the atomic structure by X-ray analysis and gave as the general formula: $(Ca,Na)_2 (Mg,Al)(Si,Al)_2O_7$.

The substitution of Al for Si in the $Si_2O_7$ radical is only possible to the extent that a trivalent element such as Al or Fe‴ occurs in the second bracket. With this proviso, it is possible to extend the formula to take into account most of the minor constituents important in slag technology, as follows: $(Ca,Na,K)_2 (Mg,Fe''Fe''',Al)(Si,Al)_2O_7$.

The present work deals with the end members

$Ca_2Al_2SiO_7$ –gehlenite
$Ca_2MgSi_2O_7$ –åkermanite
$Ca_2Fe''Si_2O_7$ –iron-åkermanite
$Ca_2Fe'''SiAlO_7$–iron-gehlenite
$NaCaAlSi_2O_7$ –sodium-melilite
$KCaAlSi_2O_7$ –potassium-melilite

and with the following systems between them:

gehlenite–åkermanite
gehlenite–iron-gehlenite
iron-gehlenite–åkermanite
gehlenite–åkermanite–iron-gehlenite
gehlenite–sodium-melilite
gehlenite–potassium-melilite
åkermanite–sodium-melilite.

During the description and discussion, it will be convenient to write the formulae of the various components in different ways. The ionic formula (*e.g.*, $Ca_2Al_2SiO_7$ for gehlenite) brings out clearly the structural relationship of the various melilites. On the other hand, the ' oxide formula ' (*e.g.*, $2CaO.Al_2O_3.SiO_2$) enables the composition to be located readily in phase diagrams. Table I gives the mineral names and the various methods of writing the formulae.

## EXPERIMENTAL METHODS

Synthetic preparations were made up from silica, alumina, ferric oxide, magnesium carbonate, sodium carbonate, potassium carbonate, and calcium carbonate of high purity. Analyses of these materials are given in Table II. The methods of preparation were as described by Nurse.[6] For the determination of melting points and solidus points, the quenching technique was used, employing special furnaces as described by Nurse and Welch.[7] Refractive indices were determined by the immersion method, using sodium light, and X-ray spacings were determined

Manuscript received 11th December, 1952.

Mr. Nurse is a Senior Principal Scientific Officer at the Building Research Station, Garston, Herts Dr. Midgley is a Senior Scientific Officer.

## Table I

### KEY TO COMPOUNDS

| | | | | | |
|---|---|---|---|---|---|
| Åkermanite | $Ca_2MgSi_2O_7$ | $2CaO.MgO.2SiO_2$ | Calcium-orthosilicate | $Ca_2SiO_4$ | $2CaO.SiO_2$ |
| Gehlenite | $Ca_2Al_2SiO_7$ | $2CaO.Al_2O_3.SiO_2$ | | | |
| Iron-åkermanite | $Ca_2Fe''Si_2O_7$ | $2CaO.FeO.2SiO_2$ | Diopside | $CaMgSi_2O_6$ | $CaO.MgO.2SiO_2$ |
| Iron-gehlenite | $Ca_2Fe'''SiAlO_7$ | $4CaO.Fe_2O_3.Al_2O_3.2SiO_2$ | Pseudo-wollastonite | $CaSiO_3$ | $CaO.SiO_2$ |
| Sodium-melilite | $NaCaAlSi_2O_7$ | $Na_2O.2CaOAl_2O_3.4SiO_2$ | Wollastonite | $CaSiO_3$ | $CaO.SiO_2$ |
| Potassium-melilite | $KCaAlSi_2O_7$ | $K_2O.2CaO.Al_2O_3.4SiO_2$ | Nepheline | $NaAlSiO_4$ | $Na_2O.Al_2O_32SiO_2$ |

## Table II

### ANALYSES OF MATERIALS USED

| | $SiO_2$, % | $Al_2O_3$, % | MgO, % | $Fe_2O_3$, % | CaO, % | $Na_2O$, % | $K_2O$, % | $SO_3$, % |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 99·72 | 0·102 | 0·035 | 0·039 | 0·004 | 0·017 | nil | 0·014 |
| $Al_2O_3$ | n.e. | 99·26 | n.e. | 0·03 | 0·04 | 0·19 | 0·04 | 0·08 |
| $CaCO_3$ | n.e. | 0·03 | 0·01 | 0·01 | 56·08 | n.e. | n.e. | 0·01 |
| $Na_2CO_3$ | nil | 0·003 | n.e. | nil | 0·01 | 73·3 | nil | 0·01 |
| $K_2CO_3$ | 0·01 | 0·01 | 0·003 | 0·001 | 0·004 | 1·78 | 87·08 | n.e. |
| $Fe_2O_3$ | 0·15 | 0·01 | 0·02 | 99·29 | nil | 0·07 | nil | trace |
| MgO* | 0·25 | 0·04 | 99·25 | 0·046 | 0·07 | n.e. | n.e. | 0·36 |

* Ignited at 1200° C. just before weighing  n.e. = Not estimated

## Table III

### VALUES OF INTERPLANAR SPACINGS OF MELILITE END MEMBERS

| Gehlenite[9] $CuK_\alpha\lambda = 1·542$ | Åkermanite[9] $CuK_\alpha\lambda = 1·542$ | Iron-gehlenite $CuK_\alpha\lambda = 1·542$ | Sodium-melilite $CuK_\alpha\lambda = 1·542$ | Iron-åkermanite[11] $FeK_\alpha\lambda = 1·9373$ |
|---|---|---|---|---|
| VVW 4·232 | VW 4·222 | VW 4·083 | VVW 4·17 | |
| WM 3·708 | W 3·717 | W 3·649 | VVW 3·80 | |
| VVW 3·439 | | | | |
| WM 3·063 | VW 3·508 | VVW 3·414 | S 3·21 | |
| S 2·846 | M 3·088 | W 3·035 | S 2·98 | S 2·874 |
| VVW 2·719 | S 2·874 | S 2·821 | S 2·81 | |
| VVW 2·534 | VVW 2·505 | VVW 2·705 | VW 2·548 | |
| | M 2·480 | | | |
| M 2·432 | W 2·426 | VVW 2·517 | W 2·392 | S 2·499 |
| M 2·407 | WM 2·386 | M 2·398 | W 2·319 | |
| M 2·396 | WM 2·318 | M 2·291 | W 2·267 | |
| M 2·297 | W 2·283 | VVW 2·181 | M 2·069 | |
| M 2·287 | VVW 2·223 | WM 2·026 | VW 2·014 | |
| VW 2·193 | VVW 2·111 | VW 1·847 | S 1·965 | M 2·199 |
| VVW 2·116 | M 2·039 | VW 1·812 | VW 1·908 | M 2·036 |
| WM 2·040 | VW 1·996 | VW 1·754 | VVW 1·862 | |
| VW 1·966 | WM 1·961 | VW 1·723 | VW 1·831 | |
| WM 1·922 | WM 1·902 | S 1·629 | VW 1·788 | M 1·762 |
| W 1·865 | VW 1·859 | VVW 1·510 | S 1·736 | |
| W 1·854 | WM 1·849 | VW 1·433 | WM 1·700 | W 1·699 |
| WM 1·813 | WM 1·779 | MS 1·374 | WM 1·677 | |
| S 1·755 | MS 1·763 | VVW 1·318 | MS 1·603 | |
| S 1·752 | W 1·734 | W 1·248 | M 1·584 | |
| W 1·720 | VVW 1·670 | W 1·182 | WM 1·492 | |
| VVW 1·707 | VVW 1·655 | | WM 1·462 | |
| W 1·632 | W 1·643 | | WM 1·421 | |
| W 1·628 | W 1·599 | | VVW 1·395 | |
| VW 1·613 | VW 1·537 | | S 1·374 | |
| VVW 1·547 | VW 1·515 | | S 1·361 | |
| M 1·516 | WM 1·508 | | VVW 1·334 | |
| VW 1·474 | VW 1·487 | | M 1·304 | |
| VVW 1·445 | W 1·470 | | M 1·269 | |
| W 1·435 | VVW 1·456 | | | |
| VW 1·423 | WM 1·436 | | | |
| VVW 1·410 | WM 1·431 | | | |
| VW 1·387 | W 1·407 | | | |
| M 1·374 | VVW 1·398 | | | |
| W 1·359 | W 1·386 | | | |
| | M 1·385 | | | |

S = strong
MS = medium strong
M = medium
WM = weak medium
W = weak
VW = very weak
VVW = very very weak

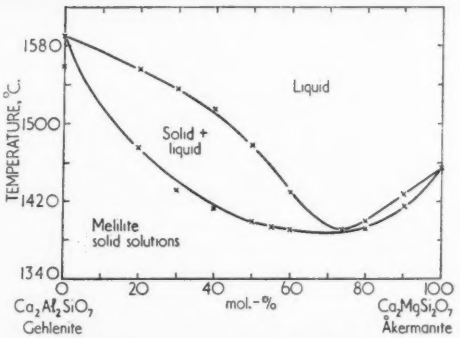



**Fig. 1—Equilibrium diagram for system gehlenite–åkermanite (after Osborn and Schairer[8])**

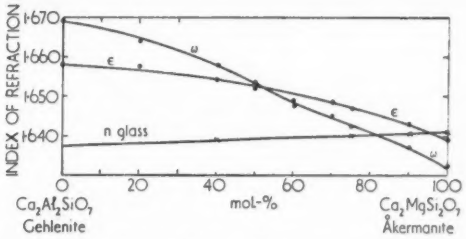



**Fig. 2—Refractive indices in system gehlenite–åkermanite (after Ferguson and Buddington[3])**

using a 9-cm. powder camera with filtered $CuK_\alpha$ radiation. Any unusual procedures or techniques necessary for special systems will be described when dealing with those systems.

## PROPERTIES OF THE END MEMBERS

### Gehlenite ($Ca_2Al_2SiO_7$)

Synthetic gehlenite melts at 1590° C.[8] It crystallizes in short-prisms with distinct basal cleavage. It is uni-axial negative, with refractive indices $\varepsilon = 1{\cdot}658$, $\omega = 1{\cdot}669$, and it has a unit cell of $c = 5{\cdot}067$Å., $a = 7{\cdot}690$Å. Powder X-ray spacings[9] for this and the following end members are given in Table III.

### Åkermanite ($Ca_2MgSi_2O_7$)

Synthetic åkermanite melts at 1454° C.[8] It is uni-axial positive, with refractive indices $\varepsilon = 1{\cdot}639$, $\omega = 1{\cdot}632$, and it has a unit cell of $c = 5{\cdot}010$Å., $a = 7{\cdot}843$Å.

Osborn and Schairer[8] and Bowen, Schairer, and Posnjak[10] have suggested that åkermanite decomposes at intermediate temperatures. The evidence for this is that åkermanite glass, when devitrified at 1375° C., gave only åkermanite, whereas, at 1050° C., $Ca_2SiO_4$ was also formed. Moreover, large homogeneous åkermanite crystals grown from sodium tungstate yielded inclusions of the general appearance of diopside when they were annealed below 1325° C. Both these experiments have been repeated by the present authors, but only pure åkermanite was obtained, even after annealing for 48 hr. However,

**Table IV**

**QUENCHING EXPERIMENTS IN THE SYSTEM GEHLENITE–IRON-GEHLENITE**

| Refractive Indices | | | Composition, mol.-% | | Temperature, ° C. | | | |
|---|---|---|---|---|---|---|---|---|
| *n* Glass | ε | ω | Gehlenite | Iron-gehlenite | All Crystalline | Crystalline + Glass | Glass + Crystalline | All Glass |
| 1·639 | 1·658 | 1·669 | 100 | 0 | ... | ... | ... | 1590 |
| 1·651 | 1·664 | 1·673 | 90 | 10 | 1565 | 1570 | 1585 | 1590 |
| 1·657 | 1·670 | 1·681 | 80 | 20 | 1500 | 1505 | 1575 | 1580 |
| 1·678 | 1·684 | 1·693 | 60 | 40 | 1430 | 1435 | 1545 | 1550 |
| 1·698 | 1·691 | 1·698 | 50 | 50 | 1390 | 1395 | 1525 | 1530 |
| 1·705 | 1·696 | 1·704 | 40 | 60 | 1355 | 1360 | 1510 | 1515 |
| 1·730 | 1·711 | 1·715 | 20 | 80 | 1305 | 1310 | 1415 | 1420 |
| 1·770 | 1·723 | 1·726 | 0 | 100 | ... | ... | ... | 1285 |

**Table V**

**QUENCHING EXPERIMENTS IN THE SYSTEM ÅKERMANITE–IRON-GEHLENITE**

| Refractive Indices | | | Composition, mol.-% | | Temperature, ° C. | | | |
|---|---|---|---|---|---|---|---|---|
| *n* Glass | ε | ω | Åkermanite | Iron-gehlenite | All Crystalline | Crystalline + Glass | Glass + Crystalline | All Glass |
| 1·641 | 1·639 | 1·632 | 100 | 0 | ... | ... | ... | 1454 |
| 1·655 | 1·650 | 1·645 | 90 | 10 | 1410 | 1415 | 1430 | 1435 |
| 1·665 | 1·657 | 1·654 | 80 | 20 | 1375 | 1380 | 1395 | 1402 |
| 1·685 | 1·661 | 1·660 | 65 | 35 | 1340 | 1345 | 1345 | 1350 |
| 1·690 | 1·674 | 1·675 | 60 | 40 | 1330 | 1335 | 1340 | 1345 |
| 1·699 | 1·684 | 1·686 | 50 | 50 | 1315 | 1320 | 1335 | 1340 |
| | 1·693 | 1·695 | 40 | 60 | 1305 | 1310 | 1335 | 1340 |
| 1·740 | | | 25 | 75 | 1290 | 1300 | 1335 | 1340 |
| 1·750 | 1·716 | 1·720 | 10 | 90 | ... | ... | 1315 | 1320 |
| 1·770 | 1·723 | 1·726 | 0 | 100 | ... | ... | ... | 1285 |

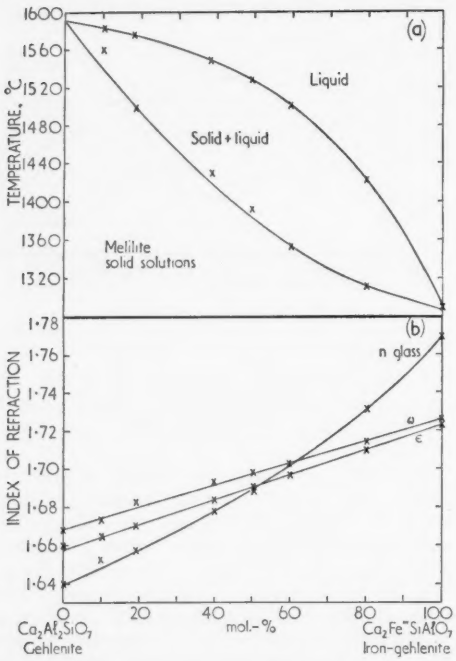



**Fig. 3—System gehlenite–iron-gehlenite: (*a*) Equilibrium diagram; (*b*) change in refractive indices**

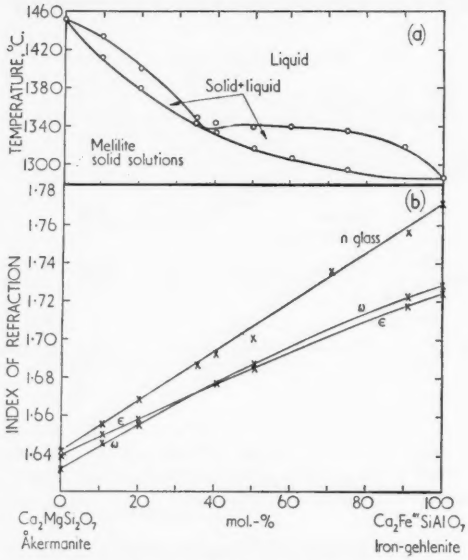



**Fig. 4—System åkermanite–iron-gehlenite: (*a*) Equilibrium diagram; (*b*) change in refractive indices**

mixtures of åkermanite with 0·2% $Ca_2SiO_4$ or 0·2% $CaMgSi_2O_6$ gave a single melilite phase at 1350–1375° C., but on annealing at 1200° C. they developed a ' peg structure ' of the second phase.

It therefore seems that pure åkermanite is stable at intermediate temperatures, but that slightly impure material may appear to decompose because of exsolution of the impurity dissolved at higher temperatures. It is interesting to note that most melilites in slags or rocks produced by the cooling of liquids exhibit ' peg structure,' but not in those that are produced by reaction in the solid state, such as contact-metamorphosed limestones (*e.g.*, Carlingford).

**Iron-åkermanite ($Ca_2Fe''Si_2O_7$)**

Iron-åkermanite is stable only below 775° C.[10] It does not therefore occur in contact with liquid in the ternary system CaO–FeO–$SiO_2$, the liquidus temperatures being too high. Above 775° C. it decomposes into wollastonite, $CaSiO_3$, and lime-iron olivine, $CaFeSiO_4$. It has been prepared by devitrifying glass of its own composition below 775° C., and is uni-axial negative, with refractive indices $\varepsilon = 1{\cdot}673$, $\omega = 1{\cdot}690$. No systems containing ferrous iron have been studied in the present investigation, because this work is

## Table VI

### QUENCHING EXPERIMENTS IN SYSTEM GEHLENITE–ÅKERMANITE–IRON-GEHLENITE

| Refractive Indices | | | Composition, mol.-% | | | Temperature, ° C. | | | |
|---|---|---|---|---|---|---|---|---|---|
| *n* Glass | ε | ω | Gehlenite | Åkermanite | Iron-gehlenite | All Crystalline | Crystalline + Glass | Glass + Crystalline | Glass |
| 1·710 | 1·692 | 1·699 | 20 | 20 | 60 | 1330 | 1335 | 1415 | 1420 |
| 1·685 | 1·682 | 1·688 | 30 | 30 | 40 | 1335 | 1340 | 1445 | 1450 |
| 1·656 | 1·666 | 1·672 | 60 | 20 | 20 | 1420 | 1425 | 1520 | 1525 |
| 1·685 | 1·665 | 1·666 | 20 | 60 | 20 | 1345 | 1350 | 1370 | 1375 |
| 1·658 | 1·660 | 1·659 | 10 | 70 | 20 | 1345 | 1350 | 1355 | 1360 |
| 1·651 | 1·660 | 1·665 | 60 | 30 | 10 | 1415 | 1420 | 1500 | 1505 |
| 1·642 | 1·655 | 1·654 | 25 | 65 | 10 | 1355 | ... | ... | 1360 |
| 1·655 | 1·654 | 1·652 | 20 | 70 | 10 | 1350 | 1355 | 1355 | 1360 |
| 1·655 | 1·655 | 1·653 | 45 | 50 | 5 | 1380 | 1385 | 1435 | 1440 |
| 1·655 | 1·650 | | 30 | 65 | 5 | 1370 | 1375 | 1385 | 1390 |
| 1·657 | 1·653 | 1·650 | 25 | 70 | 5 | 1360 | 1365 | 1365 | 1370 |
| | | | 10 | 50 | 40 | 1335 | 1340 | 1350 | 1355 |
| | | | 10 | 40 | 50 | 1315 | 1320 | 1375 | 1380 |
| | | | 30 | 20 | 50 | 1335 | 1340 | 1465 | 1470 |
| | | | 40 | 20 | 40 | 1355 | 1360 | 1475 | 1480 |
| | | | 40 | 40 | 20 | 1365 | 1370 | 1460 | 1465 |
| | | | 30 | 40 | 30 | 1355 | 1360 | 1435 | 1440 |

proceeding at the Geophysical Laboratory, Washington.

**Iron-gehlenite ($Ca_2Fe'''SiAlO_7$)**

Iron-gehlenite has not previously been described. It melts at 1285° C.; it is tetragonal, uni-axial negative, with refractive indices $\varepsilon = 1{\cdot}723$, $\omega = 1{\cdot}726$. It has a probable unit cell of $c = 4{\cdot}855$Å., $a = 7{\cdot}54$Å.

**Sodium-melilite ($NaCaAlSi_2O_7$)**

Sodium-melilite is also a new compound. It is stable only below 1080° ± 10° C. It can be made in the pure state by devitrifying glass of its own composition below this temperature. At 1080° ± 10° C. it decomposes to give wollastonite, $CaSiO_3$, and nepheline, $NaAlSiO_4$. It is tetragonal, uni-axial negative, with refractive indices $\varepsilon = 1{\cdot}575$, $\omega = 1{\cdot}580$. The unit cell is probably $c = 4{\cdot}809$Å., $a = 8{\cdot}511$Å.

**Potassium-melilite ($KCaAlSi_2O_7$)**

This composition yields a mixture of wollastonite, $CaSiO_3$, and kaliophilite at all temperatures below

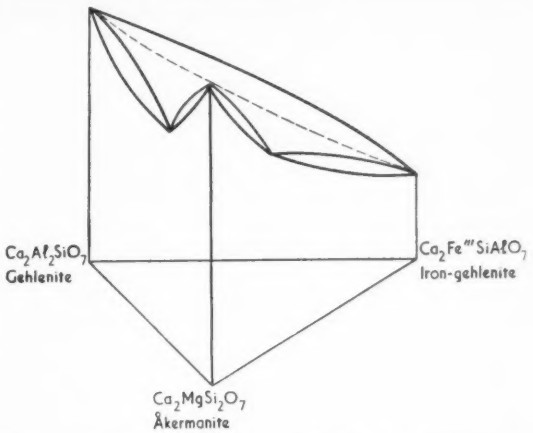



**Fig. 6—Ternary system gehlenite–iron-gehlenite–åkermanite**

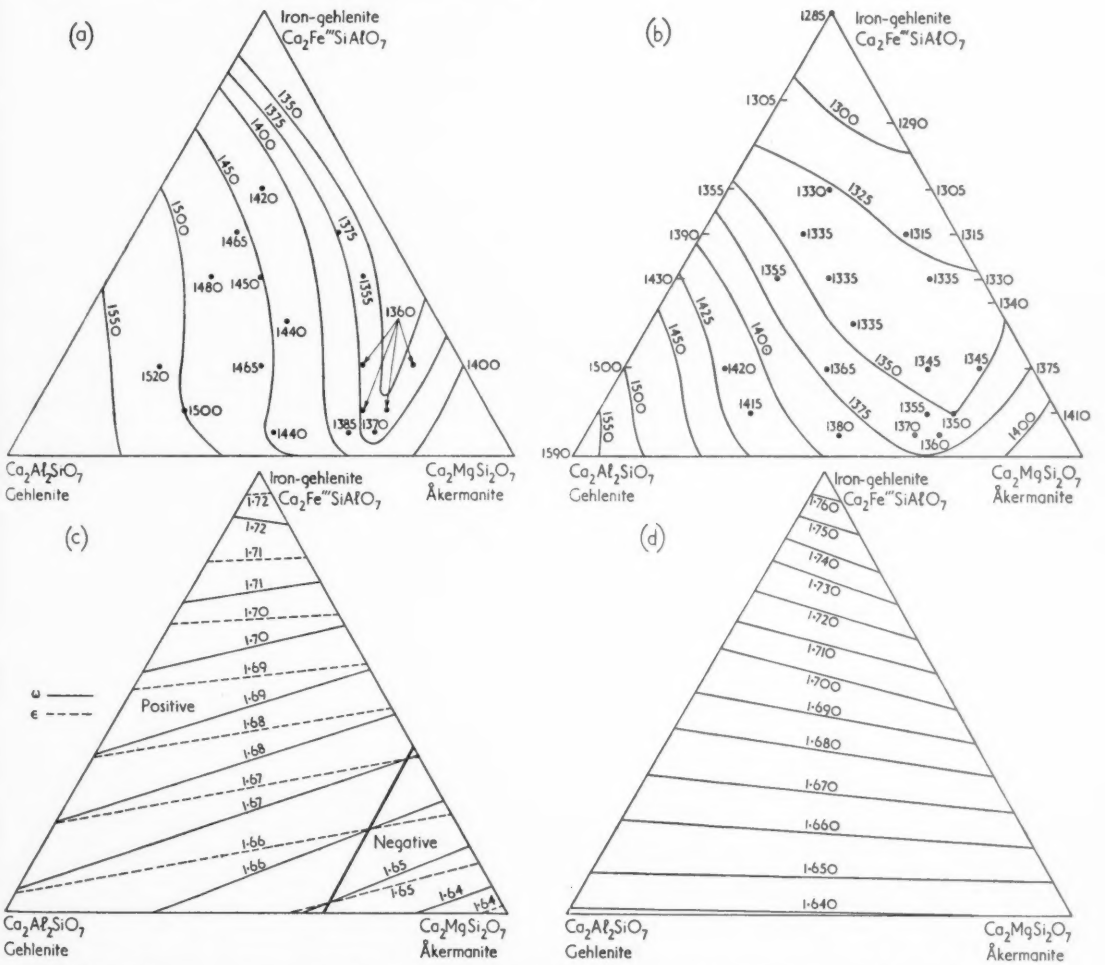



**Fig. 5—Ternary system gehlenite–åkermanite–iron-gehlenite: (*a*) Isothermus of liquidus surface; (*b*) isothermus of solidus surface; (*c*) change in refractive indices; (*d*) isofracts of glasses in system**

the solidus. It is to be presumed that the large K ion cannot be accommodated in the melilite structure to the extent indicated by the formula $CaKAlSi_2O_7$. That it can enter to some extent is shown by the fact that up to 20% of the hypothetical molecule will form a solid solution with gehlenite (*see* p. 130).

## BINARY SYSTEMS OF THE TERNARY SYSTEM GEHLENITE–ÅKERMANITE–IRON-GEHLENITE

### System Gehlenite–Åkermanite

The system $Ca_2Al_2SiO_7$–$Ca_2MgSi_2O_7$, as originally reported,[3] has been slightly revised by Osborn and Schairer.[8] The corrected diagram is reproduced as Fig. 1. Refractive indices are plotted in Fig. 2.

### System Gehlenite–Iron-gehlenite

The equilibrium diagram for this system (Fig. 3*a*) has been constructed from the data given in Table IV, which also includes the refractive indices of the various mixes. A continuous series of solid solutions is formed without a singular point. Figure 3*b* is the refractive indices diagram.

### System Åkermanite–Iron-gehlenite

The experimental data in Table V were used to construct the equilibrium diagram (Fig. 4*a*) that represents a solid-solution series with a singular point, as in the system åkermanite–gehlenite. Refractive indices are plotted in Fig. 4*b*. In this system the solidus curve was difficult to determine owing to the ease with which melts were supercooled. The supercooled glasses devitrified readily and produced quench growths. It was therefore necessary to determine this curve from completely crystalline preparations, observing the temperature at which liquid first formed.

## THE TERNARY SYSTEM GEHLENITE–ÅKERMANITE–IRON-GEHLENITE

The bounding binary systems having been established, the ternary system was delineated; the addi-

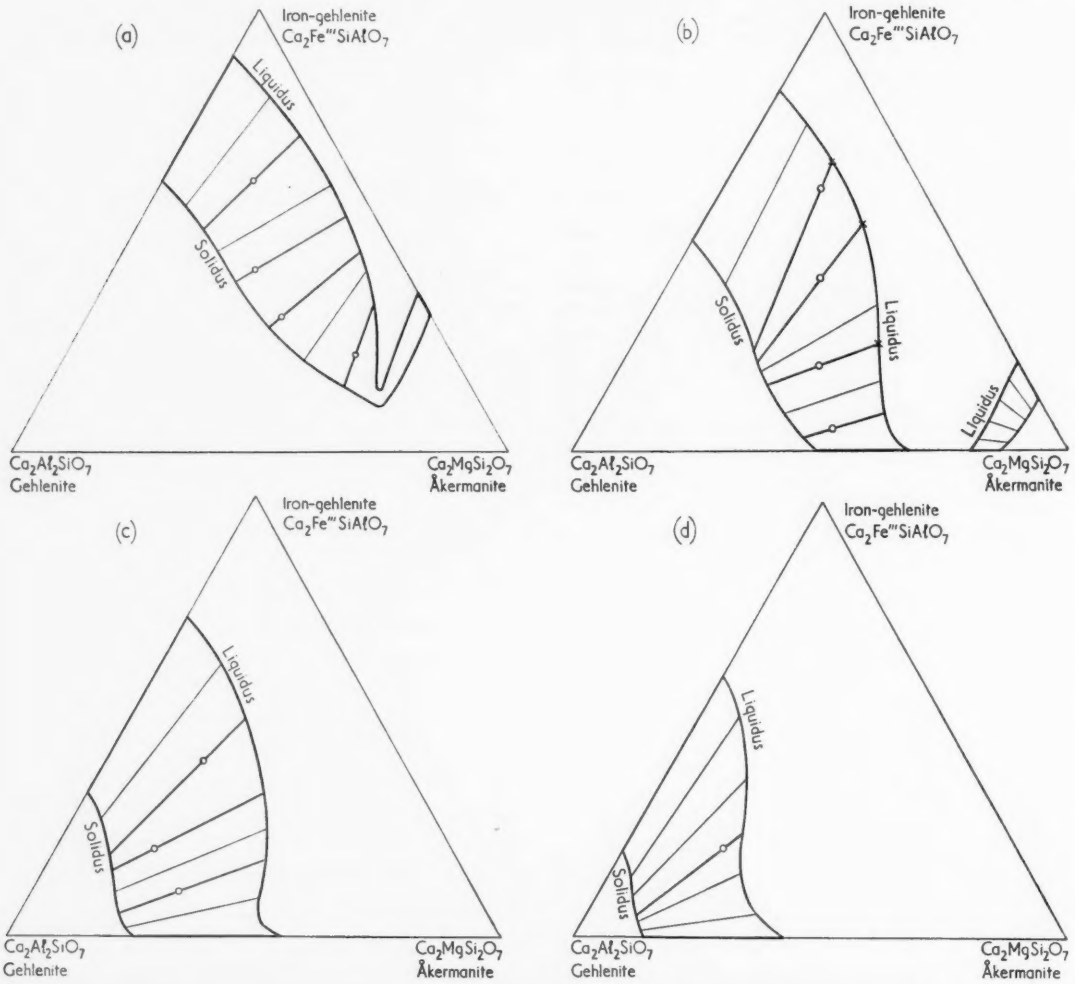



**Fig. 7—Isothermal plane at (*a*) 1350° C., (*b*) 1400° C., (*c*) 1450° C., (*d*) 1500° C.**

**Table VII**

**REFRACTIVE INDICES AND COMPOSITION OF PHASES PRODUCED AT VARIOUS TEMPERATURES**

| Refractive Indices | | | Composition of Liquid, mol.-% | | | Composition of Crystals, mol.-% | | |
|---|---|---|---|---|---|---|---|---|
| Temperature, °C. | *n* Glass | *n* Crystalline | Åkermanite | Gehlenite | Iron-Gehlenite | Åkermanite | Gehlenite | Iron-Gehlenite |
| 1520 | 1·660 | ... | 20 | 60 | 20 | ... | ... | ... |
| 1500 | 1·665 | 1·668 | 22 | 54 | 24 | 11 | 95 | 4 |
| 1480 | 1·670 | 1·670 | 26 | 46 | 28 | 11 | 78 | 10 |
| 1460 | 1·675 | 1·674 | 34 | 36 | 30 | 11 | 75 | 14 |
| 1450 | 1·770 | 1·674 | 39 | 35 | 26 | 12 | 72 | 16 |
| 1440 | 1·660 | 1·675 | 46 | 35 | 19 | 14 | 66 | 20 |
| 1420 | ... | 1·672 | ... | ... | ... | 20 | 60 | 20 |

tional data are given in Table VI. A complete series of solid solutions was formed. Figure 5*a* represents the projection of the liquidus surface on to the composition triangle, temperatures being represented by contours. Figure 5*b* is a similar projection of the solidus surface. In Fig. 5*c* the refractive index surface is projected for the two refractive indices of the crystalline phase, and in Fig. 5*d* the isofracts are those of the corresponding glasses. Figure 6 is a perspective drawing of the solid model, showing the solidus and liquidus when temperature is plotted vertically on the composition triangle as base. The valley separating åkermanite-like from gehlenite-like solid solutions approximately coincides with the isotropic melilite compositions.

Crystallization paths in ternary systems have been discussed theoretically by Marsh[12] and by Hall and Insley.[13] To facilitate the estimation of paths for any composition, isothermal sections in Figs. 7*a–d* have been prepared. In these diagrams, the boundary curves have a high degree of accuracy, being obtained from Figs. 5*a* and *b*, but the tie lines have been drawn by using as a basis a very limited number of compositions for which paths have been completely determined. The method employed is as follows. If a mix of composition $x$ is allowed to cool to $T_1$ just below its liquidus temperature, crystals will appear, and, if this mix is quenched, the liquid will give a glass of refractive index $G_1$ and the crystals will have indices of $n_1$ and $n'_1$. The composition of the liquid is given by the intersection of the glass isofract $G_1$

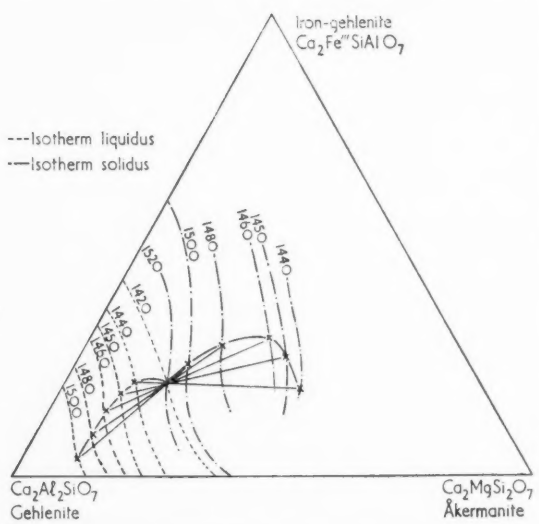


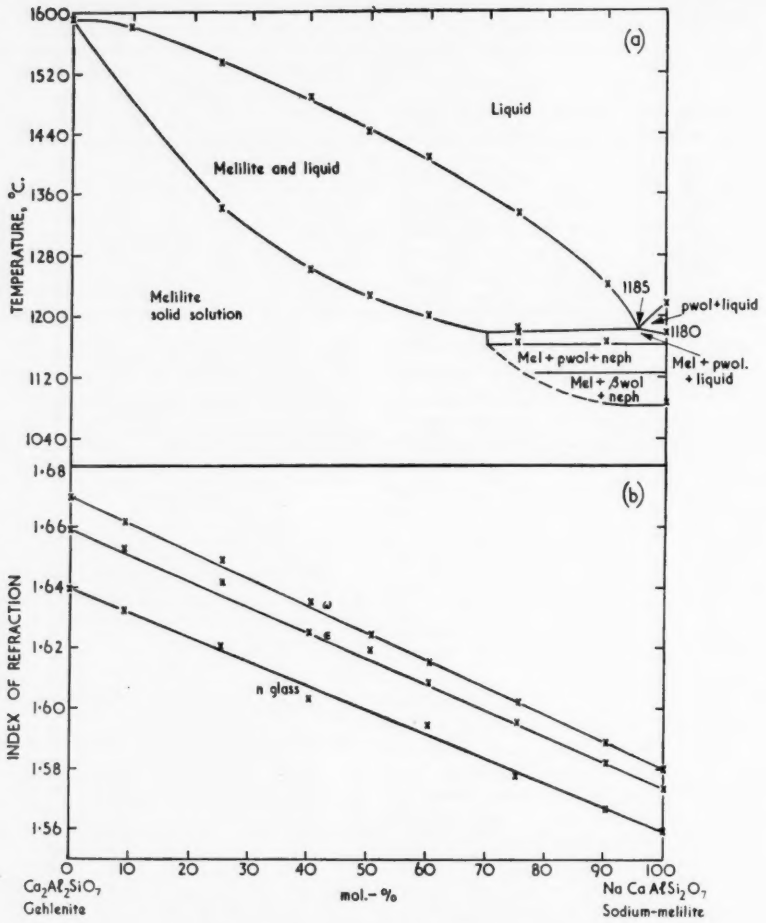

**Fig. 8—Crystallization path in system iron-gehlenite–gehlenite–åkermanite**

**Table VIII**

**QUENCHING EXPERIMENTS IN SYSTEM GEHLENITE–SODIUM-MELILITE**

| Composition, mol.-% | | Temp., °C. | Phases Present* |
|---|---|---|---|
| Gehlenite | Sodium-melilite | | |
| 100 | 0 | 1590 | glass |
| 100 | 0 | 1585 | melilite |
| 90 | 10 | 1580 | glass + trace melilite |
| 90 | 10 | 1585 | glass |
| 75 | 25 | 1535 | glass |
| 75 | 25 | 1530 | glass + melilite |
| 75 | 25 | 1340 | melilite + trace glass |
| 75 | 25 | 1335 | melilite |
| 60 | 40 | 1490 | glass |
| 60 | 40 | 1485 | glass + trace melilite |
| 60 | 40 | 1265 | melilite + trace glass |
| 60 | 40 | 1260 | melilite |
| 50 | 50 | 1445 | glass |
| 50 | 50 | 1440 | glass + trace melilite |
| 50 | 50 | 1235 | melilite + trace glass |
| 50 | 50 | 1230 | melilite |
| 40 | 60 | 1410 | glass |
| 40 | 60 | 1405 | glass + trace melilite |
| 40 | 60 | 1205 | melilite + trace glass |
| 40 | 60 | 1200 | melilite |
| 25 | 75 | 1340 | glass |
| 25 | 75 | 1335 | glass + trace melilite |
| 25 | 75 | 1170 | glass + mel + pwol |
| 25 | 75 | 1160 | melilite + pwol + neph |
| 10 | 90 | 1240 | glass |
| 10 | 90 | 1235 | glass + trace melilite |
| 10 | 90 | 1185 | glass + melilite |
| 10 | 90 | 1170 | mel + pwol + glass |
| 10 | 90 | 1165 | mel + pwol + neph |
| 0 | 100 | 1210 | glass |
| 0 | 100 | 1205 | glass + pwol |
| 0 | 100 | 1185 | glass + pwol |
| 0 | 100 | 1180 | glass + pwol + mel |
| 0 | 100 | 1170 | glass + pwol + mel |
| 0 | 100 | 1165 | glass + pwol + mel |
| 0 | 100 | 1160 | mel + pwol + neph |
| 0 | 100 | 1090 | mel + pwol + neph |
| 0 | 100 | 1080 | melilite |

* pwol = pseudo-wollastonite, neph = nepheline, mel = melilite




mel = melilite pwol = pseudo-wollastonite
neph = nepheline βwol = low-temperature wollastonite

**Fig. 9—System gehlenite–sodium-melilite: (*a*) Equilibrium diagram; (*b*) change in refractive indices**

and the liquidus isotherm $T_1$; the composition of the crystalline phase is given by the intersection of the isofracts $n_2$ and $n'_2$ (crystalline phase) with the solidus isotherm $T_2$. This then gives the solid phase in equilibrium with the liquid. The process is repeated at $T_2$ and $T_3$, etc., until $T_n$ is reached, this being the solidus temperature of the mix $x$. There is thus produced a series of points representing the change in composition of the solid phase on cooling, and also the change in composition of the liquid. As an example, Table VII gives the results obtained for a mix of composition 60% gehlenite–20% åkermanite–20% iron-gehlenite (molecular percentages), and the derived crystallization path is plotted in Fig. 8.

## SODIUM-BEARING MELILITES

### System Gehlenite–Sodium-melilite

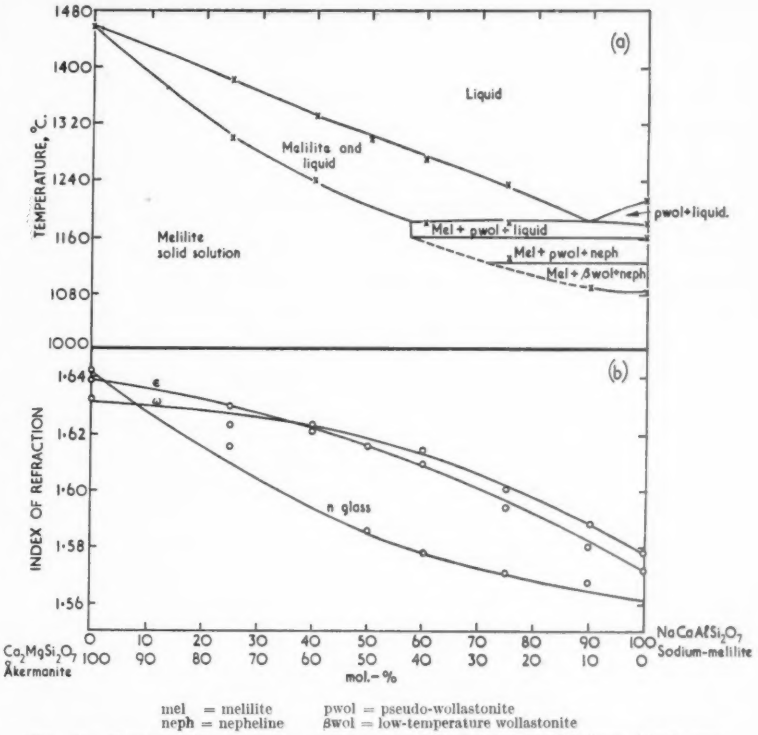
Sodium-melilite, $NaCaAlSi_2O_7$, lies in the quaternary system $Na_2O$–$CaO$–$Al_2O_3$–$SiO_2$ between wollastonite, $CaSiO_3$, and nepheline, $NaAlSiO_4$. This system has been investigated by Foster,[14] who failed to detect a melilite phase, although he suspected its presence; he showed a true binary system between the components, although his experimental data show three phases to have been present at times. Since sodium-melilite decomposes without melting, it is best prepared by annealing glass of the appropriate composition, for one month, at about 900° C. Such a preparation gives an X-ray powder pattern of melilite type, but it is not very suitable for optical study. An equimolecular mixture of wollastonite and nepheline held at 900° C. for two months showed, on X-ray analysis, a mixture of nepheline, wollastonite, and sodium-melilite. This indicates that sodium-melilite can be formed as a stable phase by reaction between wollastonite and nepheline if it is reacted below the decomposition temperature of sodium-melilite, *i.e.*, 1080° ± 10° C. A mixture of 60 mol.-% of wollastonite and 40 mol.-% of nepheline, when cooled slowly from the molten state, gave better crystals of sodium-melilite, which could be used for optical study. This also afforded confirmatory evidence that the $CaSiO_3$–

$NaAlSiO_4$ join is interrupted at the sodium-melilite composition ($NaCaAlSi_2O_7$), as only $CaSiO_3$ and $NaCaAlSi_2O_7$ were present in the completely crystalline mass. Quenches at intermediate temperatures suggested that the system $CaSiO_3$–$NaAlSiO_4$ is in fact quaternary, but the crystallization paths were extremely complicated and the experimental evidence serves only to establish $CaSiO_3$–$NaCaAlSi_2O_7$ as an Alkemade join.

The pseudo-binary system gehlenite–sodium-melilite was established by means of data given in Table VIII, and is shown in Fig. 9*a*. It is truly binary over most of the composition range, the decomposition of sodium-melilite intervening over only a short range. Refractive indices are shown in Fig. 9*b*.

**System Åkermanite–Sodium-melilite**

This system is again only pseudo-binary, because of the decomposition of sodium-melilite. It lies in the plane åkermanite–nepheline–wollastonite, which forms part of the quinary system CaO–MgO–$Al_2O_3$–$Na_2O$–$SiO_2$. The equilibrium diagram, established by the data in Table IX, is given in Fig. 10*a*, and the refractive indices are shown in Fig. 10*b*. Here again, there is a change of optical sign, and an isotropic melilite is produced at a composition approximating to 35% sodium-melilite.




mel = melilite pwol = pseudo-wollastonite
neph = nepheline βwol = low-temperature wollastonite

**Fig. 10—System åkermanite–sodium-melilite: (*a*) Equilibrium diagram; (*b*) changes in refractive indices**

**Discussion on Sodium-bearing Melilites**

A number of authors have suggested mechanisms

## Table IX

### QUENCHING EXPERIMENTS IN SYSTEM ÅKERMANITE–SODIUM-MELILITE

| Composition, mol.-% | | Temp., °C. | Phases Present* | Composition, mol.-% | | Temp., °C. | Phases Present* |
|---|---|---|---|---|---|---|---|
| Åkermanite | Sodium-melilite | | | Åkermanite | Sodium-melilite | | |
| 100 | 0 | 1455 | glass | 25 | 75 | 1240 | glass |
| 100 | 0 | 1450 | glass + trace melilite | 25 | 75 | 1230 | glass + melilite |
| 75 | 25 | 1380 | glass | 25 | 75 | 1185 | melilite + glass |
| 75 | 25 | 1375 | glass + trace melilite | 25 | 75 | 1170 | mel + pwol + glass |
| 75 | 25 | 1300 | melilite + glass | 25 | 75 | 1140 | mel + pwol + neph |
| 75 | 25 | 1295 | melilite | 25 | 75 | 1130 | melilite |
| 60 | 40 | 1330 | glass | 10 | 90 | 1180 | glass |
| 60 | 40 | 1325 | glass + trace melilite | 10 | 90 | 1120 | mel + pwol + neph |
| 60 | 40 | 1245 | melilite + glass | 10 | 90 | 1090 | melilite |
| 60 | 40 | 1240 | melilite | 0 | 100 | 1210 | glass |
| 50 | 50 | 1300 | glass | 0 | 100 | 1205 | glass + pwol |
| 50 | 50 | 1290 | glass + melilite | 0 | 100 | 1185 | glass + pwol |
| 40 | 60 | 1270 | glass | 0 | 100 | 1180 | glass + pwol + mel |
| 40 | 60 | 1265 | glass + melilite | 0 | 100 | 1170 | glass + pwol + mel |
| 40 | 60 | 1200 | melilite + glass | 0 | 100 | 1165 | glass + pwol + mel |
| 40 | 60 | 1185 | melilite + glass | 0 | 100 | 1160 | mel + pwol + neph |
| 40 | 60 | 1180 | mel + pwol + glass | 0 | 100 | 1090 | mel + pwol + neph |
| | | | | 0 | 100 | 1080 | melilite |

* pwol = pseudo-wollastonite, neph = nepheline, mel = melilite

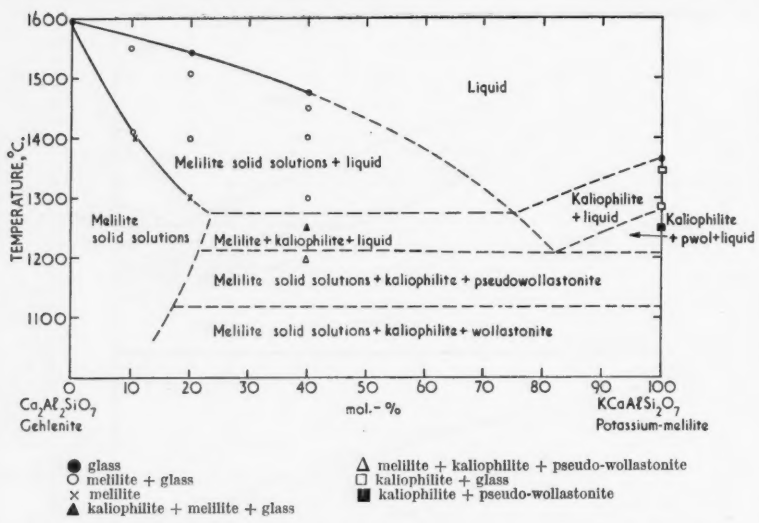



**Fig. 11—Pseudo-binary system gehlenite–potassium-melilite in system gehlenite–wollastonite–kaliophilite**

to account for the presence of sodium in melilites derived from alkaline rocks. Smalley[15] suggested that nepheline could enter into solid solution with gehlenite, and he also put forward the reaction series:

$$2NaAlSiO_4 + Ca_2Al(SiAl)O_7 \rightarrow CaSiO_3 + 2NaAlO_2 + CaAl_2Si_2O_8$$

$$NaAlSiO_4 + CaSiO_3 \rightarrow NaCaAlSi_2O_7.$$

Assuming that the two melilites would enter into solid solution, this means that nepheline would react with gehlenite to form a sodium-bearing melilite and sodium aluminate. The latter, however, has never been reported as a rock-forming mineral. Goldsmith[16] suggested that a sodium silicate, $Na_2Si_3O_7$, goes into solid solution with gehlenite, but not with åkermanite. He states that sodium-melilite, if it existed, would be a mixture of gehlenite and sodium silicate.

If interstitial substitution is excluded as being unlikely with substances of such structural complexity as those under discussion, the extensive and, in most cases, complete solid solution now reported can only be explained on the basis that the end members are—if not identical—very similar in structural type. The present work, in demonstrating the existence of a sodium-melilite, gives a much more satisfactory interpretation of the rôle played by sodium in the melilite series. It is also shown that, unless the eutectic temperature is very low, melilites rich in the sodium member are not likely to form in contact with liquid, but are much more likely to occur in rocks as a result of solid-state reaction. Goldsmith's[16] observation that the refractive index of gehlenite varied when it crystallized out in the presence of $Na_2O$ and $SiO_2$, but that åkermanite was unaffected under similar circumstances, is readily explained by the fact that Al ions are necessary to establish neutrality of charge when Na is introduced into the melilite structure. In the latter case, therefore, no sodium-melilite could form.

## Table X

### QUENCHING EXPERIMENTS IN SYSTEM POTASSIUM-MELILITE–GEHLENITE

| Refractive Indices | | | Composition, mol.-% | | Temperature, °C. | Phases* |
|---|---|---|---|---|---|---|
| *n* Glass | $\epsilon$ | $\omega$ | Gehlenite | Potassium-melilite | | |
| 1·639 | 1·658 | 1·669 | 100 | 0 | 1590 | glass |
| | | | 90 | 10 | 1550 | mel + glass |
| ... | 1·657 | 1·663 | 90 | 10 | 1410 | mel + glass |
| | | | 90 | 10 | 1400 | mel |
| | | | 80 | 20 | 1540 | glass |
| 1·616 | 1·653 | 1·658 | 80 | 20 | 1510 | mel + glass |
| | | | 80 | 20 | 1400 | mel + glass |
| | | | 80 | 20 | 1300 | mel |
| | | | 60 | 40 | 1480 | glass |
| | | | 60 | 40 | 1450 | glass + mel |
| 1·600 | | mix | 60 | 40 | 1400 | glass + mel |
| | | | 60 | 40 | 1300 | glass + mel |
| | | | 60 | 40 | 1250 | mel + kaliophilite + glass |
| | | | 60 | 40 | 1200 | mel + kaliophilite + wol |
| | | | 0 | 100 | 1360 | glass |
| | | | 0 | 100 | 1350 | glass + kaliophilite |
| | | | 0 | 100 | 1290 | glass + kaliophilite |
| | | | 0 | 100 | 1250 | kaliophilite + wol |

* wol = wollastonite, mel = melilite

### POTASSIUM-BEARING MELILITES

#### System Potassium-melilite–Gehlenite

Potassium-melilite, if it existed, would lie in the quaternary system $CaO$–$K_2O$–$Al_2O_3$–$SiO_2$, but it has proved to be impossible to synthesize it. The presence of $K_2O$ in natural melilites is, however, attributed to a partial solid solution of a potassium-bearing melilite, as it is possible for some potassium substitution to take place in the melilite structure before it becomes unstable.

The pseudo-binary system gehlenite–potassium-melilite has been partially investigated. The results of quenching experiments are given in Table X, and these results are plotted as an equilibrium diagram in Fig. 11. The results show that the pseudo-binary system is part of the ternary system gehlenite–pseudo-wollastonite–kaliophilite and that a solid solution of potassium-melilite in gehlenite exists to about 20%.

### Acknowledgments

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# The Chemical Constitution of Sinters

*By R. Wild, Ph.D.*

SYNOPSIS

The chemical constitutions of a number of commercial sinters and of sinters produced in the B.I.S.R.A. experimental sinter box from both lean and rich ores have been found by X-ray powder diffraction photography.

The extent to which various chemical constituents are present in the experimentally produced lean-ore sinters is directly related to the carbon content of the raw mix. A close relationship exists between the ferric oxide and the ferrous silicate content of these sinters and their strength and reducibility.

The difference in the sintering process when rich ores are used instead of lean ores, and the effect of this difference upon the properties of the resultant sinter, are discussed. 735

The physical and chemical properties of sinter vary very widely. The blast-furnace appears to be able to tolerate these variations, but certain properties are important if the furnace is to run smoothly and efficiently. The sinter must be strong enough to resist disintegration during handling and to withstand the abrasive and compressive forces met with during descent through the furnace. It should also be sufficiently reducible to ensure that it does not pass down to the bosh zone virtually unchanged, with the consequent excessive requirement of high-temperature heat.

The present paper attempts to show to what extent these properties are linked with the chemical composition of the sinter and how this is influenced by the raw materials and the sintering conditions.

#### Analytical Method

Although chemical analysis gives an accurate record of the quantity and state of oxidation of the iron present and also the amounts of the other elements in the sinter, it gives insufficient indication of the manner in which they are combined. This leaves a serious gap in the knowledge of sinter composition because, for example, the state of combination of the silica has an important bearing on the nature of the

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## Table I

### RESULTS OF DETAILED INVESTIGATION OF INDIVIDUAL SINTER LUMPS

| Sample No. | $Fe_2O_3$, % | $Fe_3O_4$, % | FeO, % | $Fe_2SiO_4$, % | CaFe. $SiO_4$, % | $CaCO_3$, % | $SiO_2$, % |
|---|---|---|---|---|---|---|---|
| | | | | **Sinter A** | | | |
| 1 | ... | 100 | ... | tr. | tr. | ... | ... |
| 2 | ... | 80 | ... | small | 20 | ... | ... |
| 3 | ... | 100 | tr. | tr. | ... | small | ... |
| 4 | ... | 60 | 20 | 5 | 15 | small | ... |
| 5 | ... | 65 | 5 | 5 | 25 | ... | ... |
| 6 | ... | 85 | small | 5 | 10 | tr. | ... |
| 7 | 10 | 90 | tr. | tr. | small | ... | ... |
| 8 | 20 | 80 | tr. | tr. | ... | ... | ... |
| | | | | **Sinter C** | | | |
| 1 | 30 | 70 | ... | small | ... | ... | ... |
| 2 | 80 | 20 | ... | ... | ... | ... | small |
| 3 | 20 | 80 | ... | small | ... | ... | ... |
| 4 | 30 | 70 | ... | small | ... | ... | ... |
| 5 | 90 | 10 | ... | ... | ... | small | small |
| 6 | 40 | 60 | tr. | small | ... | ... | ... |
| 7 | 20 | 80 | ... | small | ... | ... | ... |
| 8 | 60 | 40 | tr. | small | ... | ... | ... |
| | | | | **Sinter F** | | | |
| 1 | small | 85 | 15 | small | ... | ... | ... |
| 2 | 20 | 80 | tr. | small | ... | ... | ... |
| 3 | ... | 30 | 50 | 20 | ... | ... | ... |
| 4 | 10 | 90 | small | small | ... | ... | ... |
| 5 | ... | 85 | 10 | 5 | ... | ... | ... |
| 6 | 10 | 85 | tr. | 5 | ... | ... | ... |
| 7 | small | 80 | 10 | 10 | ... | ... | ... |
| 8 | 60 | 40 | ... | ... | ... | ... | ... |

product. Microscopic and micro-radiographical examination of sinters yields considerably more information on their structure, since the nature of the crystalline bodies can be established and the extent of the slagging can be assessed.

In this work, however, X-ray powder diffraction photography has been used to determine the sinter composition. With this technique any crystalline component present in reasonable quantity may, in general, be detected. Solid solutions between isomorphous crystalline components may be identified, and the quantities of each component may be established. By comparison with photographs of mixtures of known composition the approximate quantitative amounts of the compounds present can be obtained. Only a very small amount of material, about ½ mg., is needed for an analysis, so that the composition of the sinter at a definite point can be obtained if necessary.

## INVESTIGATION OF COMMERCIAL SINTERS

### Method of Sampling

Typical commercial sinters were obtained from various sources in 1950. A preliminary examination was made and then a number were studied in greater detail. Because of the very small size of the analytical specimen the manner in which it is chosen is important. It would be feasible, though laborious, to obtain a representative sample for analysis from a large quantity of sinter; whilst this would be of value for the comparison of average compositions, it would prevent the detection of compounds present in small overall quantities but which may be locally abundant. Therefore, after the initial preliminary investigation, a single representative lump of the chosen sinter was crushed into small fragments, a number of which were subjected to X-ray analysis.

### Preparation of Standard Reference Photographs

The photographs were taken in a 9-cm. dia. camera, using cobalt Kα radiation. Standard photographs of iron and iron oxides, and of silica, lime, etc., were prepared for reference purposes. Specimens of (*a*) fayalite ($Fe_2SiO_4$) and (*b*) calcium ferrous silicate ($CaFeSiO_4$) were prepared by heating stoichiometric quantities of (*a*) pure iron, hematite, and silica, and (*b*) pure iron, hematite, silica, and lime, to temperatures just below the melting point (about 1050° C.) in sealed, evacuated, silica capsules. The photograph obtained from fayalite contained no lines that could be associated with any iron oxide, iron, or silica, and was identical with reference photographs of this material obtained from other sources. The photograph obtained from $CaFeSiO_4$ was distinct from that of fayalite, of any calcium silicate, or of any of its constituents. Chemically, all the iron was present in the ferrous state and the total (23%) was reasonably close to the theoretical total (29%), indicating that there was at least 80% of this material in the sample.

Standard photographs of known mixtures of Fe and FeO, FeO and $Fe_3O_4$, and $Fe_3O_4$ and $Fe_2O_3$ were prepared and were used for the visual estimation of the approximate relative concentrations of iron and iron oxides in the sinters. Similarly, photographs of $Fe_2O_3$: $Fe_3O_4$: $Fe_2SiO_4$ mixtures and $Fe_3O_4$: $CaFeSiO_4$ mixtures were used to estimate silicate content.

### Composition of the Sinters

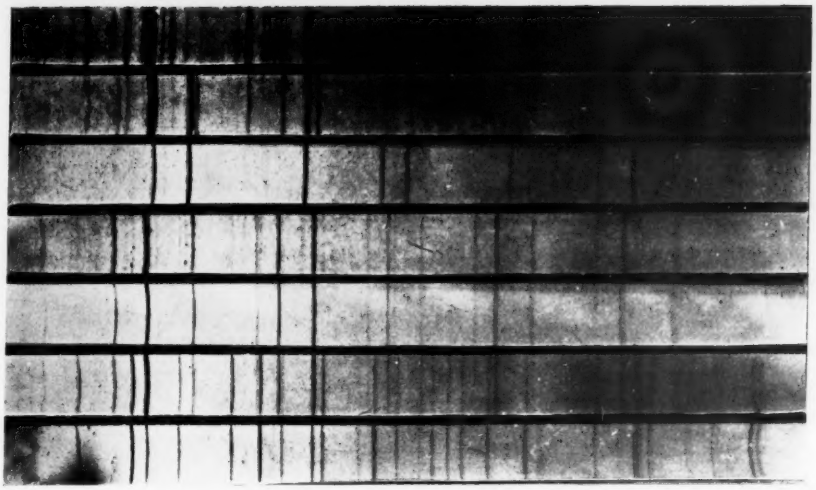
The preliminary survey of the commercial sinters showed that the main crystalline constituent of each of the sinters was magnetite, with smaller quantities of hematite, fayalite, and calcium ferrous silicate. Neither iron nor wüstite (FeO) was found in this preliminary survey, but the detailed investigation revealed that wüstite was present in considerable quantities in certain sinters, and small amounts of silica and calcium carbonate were also identified. The $CaCO_3$ was undoubtedly formed from CaO during or after the sinter cooling.

The results of the detailed investigation of individual lumps are shown in Table I. The figures in this table and in subsequent ones for iron oxide and silicate content are approximate only ($\pm$ 5%) and are percentages of the total crystalline iron, iron oxide, and iron silicate content.

Table I shows clearly that the composition of a single medium-sized lump (1–2 in.) can vary greatly—in the case of sinter *F* from mainly wüstite to predominantly hematite. Figure 1 shows X-ray diffraction photographs of three samples of this sinter, together with reference photographs of $Fe_2SiO_4$, FeO, $Fe_3O_4$, and $Fe_2O_3$. Table I also shows that free silica is present only when the degree of oxidation is high; silicates—of which only fayalite and calcium ferrous silicate were identified—are present when the sinters are more reduced.

### Relationship between Composition and Strength

With certain commercial sinters it was possible to



(*a*) $Fe_2SiO_4$

(*b*) Sample 3

(*c*) FeO

(*d*) Sample 4

(*e*) $Fe_3O_4$

(*f*) Sample 8

(*g*) $Fe_2O_3$

**Fig. 1—X-ray powder photographs of samples of sinter *F* and reference substances**

(*a*) $CaFeSiO_4$

(*b*) Sample from sinter 30

(*c*) FeO

(*d*) Sample from sinter 9

(*e*) $Fe_3O_4$

(*f*) Sample from sinter 25

(*g*) $Fe_2O_3$

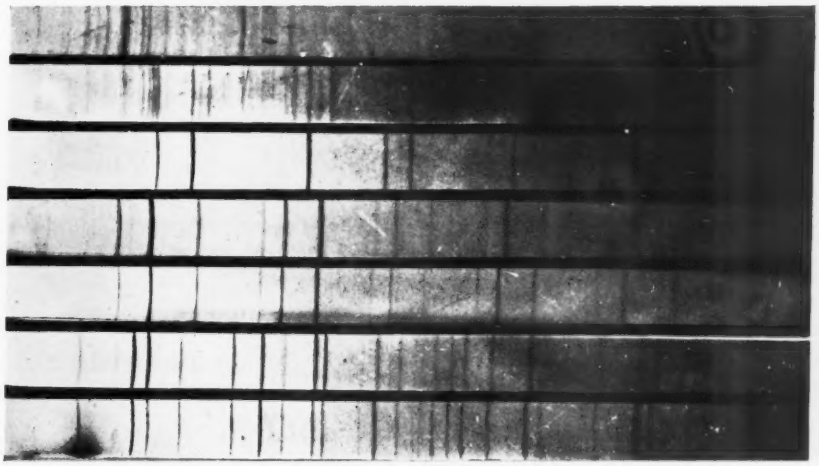
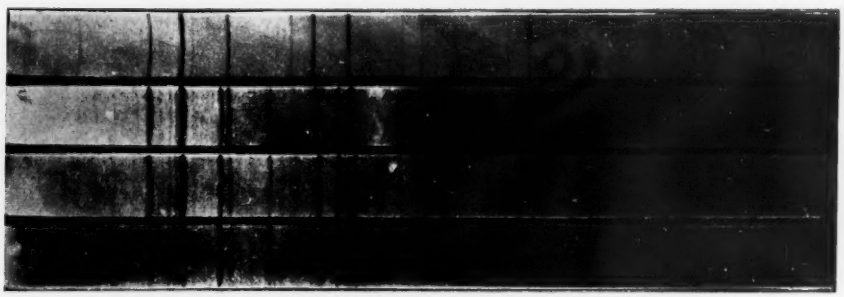


**Fig. 2—X-ray powder photographs of reference substances and sinters made in the B.I.S.R.A. experimental sinter box from Northants ore**



(*a*) $Fe_3O_4$

(*b*) Sinter 4, sample 2

(*c*) Sinter 4, sample 3

(*d*) Sinter 4, sample 1

**Fig. 3—X-ray powder photographs of sinters made in the B.I.S.R.A. experimental sinter box from Northants ore, showing increasing distortion of the $Fe_3O_4$ pattern due to solid-solution formation**

separate the material into two classes, one relatively open-textured and rather friable, the other hard and glassy. Typical samples from these two classes were examined for chemical composition and for physical properties. The porosity (determined by the S.K. method[1]), voidage, strength (determined by an impact test similar to that described by Voice, Lang, and Gledhill[2], increasing strength being denoted by increasing values of the index), and ferric oxide content (obtained from X-ray photographs of average samples of the two classes of sinter) are as follows:

| Appearance | Porosity,* % | Voidage,* % | Strength Index | $Fe_2O_3$, % |
|---|---|---|---|---|
| **Sinter B** | | | | |
| Open-textured | 12·0 | 180 | 21½ | 40 |
| Glassy | 11·4 | 150 | 31 | 5 |
| **Sinter C** | | | | |
| Open-textured | 10·6 | 180 | 23 | 80 |
| Glassy | 9·5 | 154 | 56 | 10 |
| **Sinter F** | | | | |
| Open-textured | 15·9 | 157 | 30 | 40 |
| Glassy | 2·7 | 122 | 59½ | 5 |
| **Sinter G** | | | | |
| Open-textured | 7·0 | 197 | 35½ | 60 |
| Glassy | 10·7 | 133 | 41½ | 20 |

* Calculated on the basis of solid material = 100

It is at once apparent that, in general, the more porous material, which is less strong, has a high ferric oxide content compared with the glassy, less porous material.

## EXAMINATION OF EXPERIMENTALLY MADE SINTERS

The results of the investigation of commercial sinters suggested that it would be extremely interesting to see if there were any definite relationships between chemical composition, physical and chemical properties, and the coke and flue-dust composition of the raw mix when the sintering was carried out under carefully controlled conditions. Representative samples of sinters made in the B.I.S.R.A. experimental sinter box[2] were therefore obtained and studied in the same way as the works sinters chosen for detailed examination.

### Sinters made from Northants Ore

Samples of sinter from two series of trials were examined; in one only the coke content of the raw mix had been varied, and in the other the only variable was the flue-dust content. From each sample four small representative fragments were subjected to X-ray analysis.

Table II shows the coke, flue dust, and total carbon content (carbon content of flue dust = 14·0%) of the raw mix and the approximate mean iron, iron oxide, iron silicate, and free silica content of the sinters. In these sinters the iron silicate was almost entirely calcium ferrous silicate. In one sample, where the $CaFeSiO_4$ was estimated at 30%, the CaO content, found by chemical analysis, was 8·5%, which is equivalent to 28½% of $CaFeSiO_4$.

The X-ray diffraction photographs from samples of three of these sinters are shown in Fig. 2, together with reference photographs of $CaFeSiO_4$, FeO, $Fe_3O_4$, and $Fe_2O_3$. The sample from sinter 30 contains considerable quantities of $CaFeSiO_4$, FeO, and $Fe_3O_4$, and appreciable metallic iron. The samples from sinters 9 and 25 are mainly $Fe_3O_4$ and $Fe_2O_3$, respectively.

The $Fe_3O_4$ pattern in sinter 9 is somewhat distorted, the extent of the distortion increasing towards the right-hand side, *i.e.*, where the angle of diffraction is greatest. Figure 3 shows photographs of $Fe_3O_4$ and three samples from sinter 4, where the $Fe_3O_4$ lines show an increasing displacement to the right. Such displacements indicate that a solid solution with some isomorphous crystalline body has been formed; the direction of the line shift shows that the substance forming the solid solution with the $Fe_3O_4$ has a smaller lattice parameter than magnetite, and its extent indicates that it could be only the spinel $FeAl_2O_4$ (hercynite) or, less probably, $Al_2O_3$ itself.

By a calculation based on the extent of the line shift,[3] the composition of the solid solution, assuming it to be composed solely of $Fe_3O_4$ and $FeAl_2O_4$, was found. These compositions, together with the total percentages of $Al_2O_3$ in the samples, the latter being calculated approximately from the spinel content of the samples and from their total iron content, were

## Table II

### DETAILS OF SINTERS MADE FROM NORTHANTS ORE

| Serial No. | Raw Mix | | | Sinter | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Coke, % | Flue Dust, % | Total C, % | $Fe_2O_3$, % | $Fe_3O_4$, % | FeO, % | Fe, % | Free $SiO_2$, % | Total Silicate % |
| 2 | 7 | 10 | 7·4 | .. | 70 | 15 | ... | ... | 15 |
| 4 | 6 | 10 | 6·5 | ... | 50 | 25 | ... | ... | 25 |
| 7 | 5·5 | 10 | 6·0 | 10 | 90 | tr. | ... | ... | tr. |
| 9 | 5 | 10 | 5·7 | 25 | 75 | tr. | ... | tr. | tr. |
| 11 | 4·5 | 10 | 5·2 | 30 | 70 | tr. | ... | tr. | tr. |
| 12 | 4 | 10 | 4·8 | 45 | 55 | ... | ... | small | ... |
| 15 | 3 | 10 | 4·0 | 50 | 50 | ... | ... | small | ... |
| 25 | 5 | 5 | 4·9 | 35 | 65 | ... | ... | small | ... |
| 26 | 5 | 15 | 6·4 | 5 | 90 | 5 | ... | ... | small |
| 28 | 5 | 20 | 7·1 | 10 | 85 | small | ... | ... | 5 |
| 30 | 5 | 30 | 8·4 | ... | 60 | 10 | small | ... | 30 |

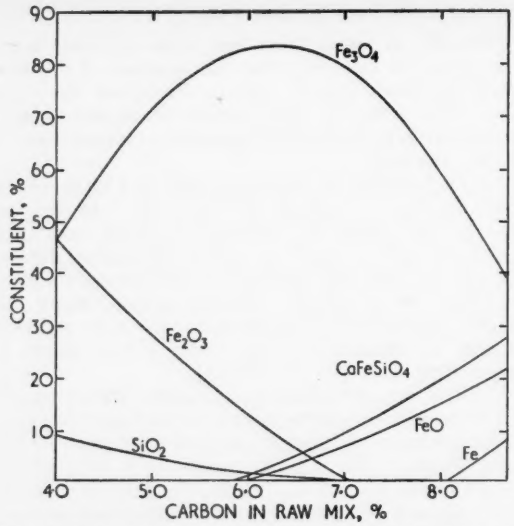



**Fig. 4—Diagrammatic representation of the effect of carbon content in the raw mix upon the constituents of sinters made from Northants ore**

as follows :

| Substance | Lattice Parameter* | $FeAl_2O_4$ in the $Fe_3O_4$–$FeAl_2O_4$ Solid Solution, % | $Al_2O_3$ in the Sinter, % |
|---|---|---|---|
| $Fe_3O_4$ | 8·375 | 0 | ... |
| Sinter sample 2 | 8·35 | 8½ | 2·5 |
| ,, ,, 3 | 8·29 | 30 | 6·2 |
| ,, ,, 1 | 8·21 | 64 | 6·3 |
| $FeAl_2O_4$ | 8·14 | 100 | ... |

* The values for $Fe_3O_4$ and $FeAl_2O_4$ were obtained from a paper by K. W. Andrews.[4]

Chemical analysis of sample 3 showed an $Al_2O_3$ content of 6·1%, which agrees with that deduced approximately from X-ray data. The increasing percentages of $FeAl_2O_4$ in the solid solution may be due partly to a decreasing total spinel content in the sinter, and partly to an increased sintering temperature brought about by a locally increased carbon content.

If the line shifts are due to $Al_2O_3$, and not to $FeAl_2O_4$, the percentages of the former in the solid solutions would be less, *i.e.*, 4, 11, and 21% respectively, and the $Al_2O_3$ content of the sinters would be about 1·9, 3·4, and 3·6% respectively. Although, in the case of sample 3, this is considerably less than that found chemically, the balance could be in the non-crystalline glassy material which cannot be identified by X-ray powder diffraction analysis.

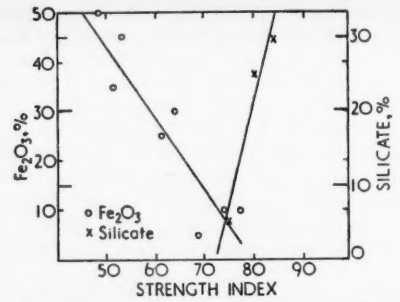



**Fig. 5—Effect of ferric oxide and ferrous silicate contents upon the strength of home-ore sinters**

The manner in which the iron silicate, free silica, iron, and iron oxide content varied with the carbon content of the raw mix is shown diagrammatically in Fig. 4. The $Fe_2O_3$ and $SiO_2$ falls rapidly with increasing carbon. The $Fe_3O_4$ rises to a maximum at about 6% of carbon and then falls again. $CaFeSiO_4$ and FeO only appear in the sinter as the carbon approaches 6%, and then increase with increasing carbon. The relative proportions of these two compounds will, of course, be determined by the amount of silica locally available. Free Fe appears only when the carbon content is abnormally high.

The sinter strengths, as determined by Voice, Lang, and Gledhill,[2] are plotted against $Fe_2O_3$ content and iron silicate content in Fig. 5. The strength increases with decreasing $Fe_2O_3$ in the sinter and increases with increasing iron silicate content.

The reducibilities of sinters 9, 15, and 30 were found in a standard reducibility test, using hydrogen at 750° C.[5] The $Fe_2O_3$ and silicate contents, degree of reduction, strength, and reducibility (reciprocal of time for 80% reduction × 100) are as follows:

| Serial No. | Degree of Reduction, % X-Ray | Degree of Reduction, % Chemical | Strength Index | Reducibility |
|---|---|---|---|---|
| 15 | 5·6 | 5·2 | 48·3 | 1·65 |
| 9 | 8·5 | 8·0 | 61·7 | 0·34 |
| 30 | 18·1 | 17·9 | 84·3 | 0·17 |

It is impossible to obtain maximum strength and maximum reducibility at the same time, the one being obtained only at the expense of the other.

These results underline the conclusion of Gillings and his co-workers[5] that the control of the carbon

## Table III

### DETAILS OF SINTERS MADE FROM GRANGESBERG ORE

| Serial No. | Raw Mix | | | Sinter | | | | |
|---|---|---|---|---|---|---|---|---|
| | Coke, % | Flue Dust, % | C, % | $Fe_2O_3$, % | $Fe_3O_4$, % | FeO, % | $FeSiO_4$, % | $SiO_2$, % |
| 1 | 2 | 10 | 3·1 | 70 | 30 | ... | ... | ... |
| 2 | 3 | 10 | 3·9 | 10 | 90 | ... | ... | tr. |
| 3 | 4 | 10 | 4·7 | 20 | 80 | ... | ... | ... |
| 4 | 5 | 10 | 5·5 | 30 | 70 | ... | ... | ... |
| 5 | 3 | 0 | 2·4 | 40 | 60 | ... | ... | tr. |
| 6 | 3 | 20 | 5·4 | 10 | 90 | ... | ... | ... |
| 7 | 3 | 30 | 6·9 | small | 95 | small | 5 | ... |

content of the raw mix is of primary importance in commercial sinter making.

**Sinter Made from Grangesberg Ore**

Samples of two series of sinters were examined; in one the coke content was varied and the flue dust was constant, and in the other the flue dust was varied.

Table III shows the coke, flue dust, and total carbon content of the raw mix and the average iron oxide and iron silicate content of the sinters. As before, four fragments of each sinter were used for analysis.

Table III shows that the relationship between the carbon content in the raw mix and the state of oxidation of the sinter is not as close as in the sinters made from home ores. Although there is a general decrease in the $Fe_2O_3$ content of the sinter as the carbon content of the raw mix increases, there are wide fluctuations. This may be due to an unfortunate choice of sinter fragments for analysis or to the fact that the lumps from which these came were taken from widely different vertical positions in the bed.

Since Grangesberg ore is a magnetite, the $Fe_2O_3$ in sinter made from it must have been produced by oxidation, whereas that found in the sinter made from Northants ore may reasonably be supposed to be material that has remained unsintered. In the latter case the $Fe_2O_3$ is, as would be expected, directly dependent upon the carbon content of the raw mix and is a source of weakness in the sinter. In the former case, also, a low carbon content in the raw mix will favour $Fe_2O_3$ production, since here the fuel is needed only to raise the temperature sufficiently to oxidize $Fe_3O_4$, which, being exothermic, maintains the mass at a temperature high enough to bring about diffusion bonding. Here the strength should, within limits, be independent of the $Fe_2O_3$ content. The reducibility should, however, be proportional to it, since oxidation can take place only when air is able to permeate the mass, so that high $Fe_2O_3$ content is indicative of a highly porous sinter. Table IV shows that the strength and reducibility do vary in this way. This agrees with Swedish experience when sintering high-grade magnetites.[6, 7] It can also be seen, by comparison with the reducibilities given on page 134, that sinters made from rich ores are considerably more reducible than sinters of comparable strength made from home ores.

The strength of the sinter containing 30% of flue dust is appreciably greater than the others; this is the only sinter in which wüstite and iron silicate (in this case $Fe_2SiO_4$) were identified (Table III). Their appearance in this sinter agrees with the results obtained from sinters made from Northants ores, since the carbon content of the raw mix is now high enough for the presence of these compounds to be anticipated (Fig. 4); the increase in strength due to silicate formation is also to be expected (Fig. 5). Since the flue dust originated from Cleveland ore, another factor is introduced into the problem.

## CONCLUSIONS

(1) With sinters made from lean ores the ferric oxide content decreases as the carbon content of the raw mix increases and this oxide is not found in sinters where the raw mix contains more than about 7% of carbon. Ferrous silicates are found in these sinters only when the carbon content of the raw mix is greater than about 6% of carbon; the amount of these silicates thereafter increases with increasing carbon in the raw mix.

(2) The strength of the sinters from lean ores decreases with increasing ferric oxide content and increases with increasing ferrous silicate content.

(3) The reducibility of these sinters decreases as their strength increases. It is very small when an appreciable quantity of silicate is present.

(4) Reasonable strength is not attained with sinters made from home ores unless some silicate is present, which suggests that the silicate plays an important part in the bonding.

(5) With sinters made from rich ores the strength is independent of the ferric oxide content and a sinter of reasonable strength can be obtained without any detectable amount of silicate being present. The presence of appreciable silicate in the sinter does, however, give added strength.

(6) The reducibility of such sinters is generally appreciably greater than those of home ores with comparable strengths. The greatest reducibility was found where the ferric oxide content was greatest.

**Table IV**

**VARIATION OF STRENGTH AND REDUCIBILITY OF SINTERS MADE FROM GRANGESBERG ORE**

| Serial No. | Raw Mix | | | Sinter | | |
|---|---|---|---|---|---|---|
| | Coke, % | Flue Dust, % | C, % | $Fe_2O_3$, % | Strength Index | Reducibility |
| 1 | 2 | 10 | 3·1 | 70 | 67 | 4·0 |
| 2 | 3 | 10 | 3·9 | 10 | 69 | 1·65 |
| 3 | 4 | 10 | 4·7 | 20 | 69 | 1·8 |
| 4 | 5 | 10 | 5·5 | 30 | 71 | 1·8 |
| 5 | 3 | 0 | 2·4 | 40 | 66 | 1·7 |
| 6 | 3 | 20 | 5·4 | 10 | 67 | 1·45 |
| 7 | 3 | 30 | 6·9 | small | 79½ | 1·35 |

## Acknowledgments

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# The Permeability of Sinter Beds

*By*

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SYNOPSIS

Sintering cannot proceed without adequate air passing through the bed. Highly permeable sinter beds need less fan horsepower for a given air flow, or, alternatively, for a given fan power, increasing the bed permeability gives greater air flow, and therefore greater sinter production. Permeability is defined, and methods of determining it are described.

Knowledge of the permeability enables modifications to the plant or process to be assessed; maximum advantage can then be taken of water additions, size grading, conditions of laying the bed, etc., to increase sinter production or produce colder sinter. Sinter output has been greatly increased by these means on one plant without any deleterious change in sinter quality. 745

## Introduction

Sintering consists essentially of the combustion of a mixture of ironstone and fuel on a down-draught grate.

The utilization of air can be very good; samples of waste gases taken from immediately below the grate have shown a $CO_2$ content as high as 20%. Average $CO_2$ contents towards the end of the process are much lower, and, owing to leaks around the sinter cake, between the pallets and rails (or trunnions), and in the dust-extraction system, the final stack gases may contain an average of only 3–4% $CO_2$. Any method of reducing these leaks is therefore worth serious consideration.

An adequate quantity of air must, however, be drawn through the bed to produce sinter, and it should be remembered that the fan horsepower is approximately proportional to the suction used.

If the sinter bed is made more permeable, the necessary air can be drawn through with a lower suction and the power cost can be reduced. In practice, with an existing plant and an insatiable demand for sinter, increased permeability means that more air can be drawn through at a lower suction for the same fan horsepower, given suitable fan characteristics. The strand speed or bed height can then be increased because of the larger air flow, and the sinter output is correspondingly greater. Fan air utilization is also increased, because at the lower suction the leakages are reduced, and there are indications that, for a given mixture, less air is needed to sinter a ton of raw material when the bed is more permeable.

## DEFINITION OF PERMEABILITY

The definition must, in some way, involve three factors—the rate of air flow per square foot of sinter bed, the suction necessary to sustain this air flow, and the bed height.

Permeability is usually defined as the flow through a unit cube of material under a unit pressure gradient, all values being expressed in self-consistent units. Therefore,

$$P = \frac{F}{A} \cdot \frac{h}{s},$$

where $F$ = flow, $A$ = area, $h$ = bed height, and $s$ = applied suction.

This formula is usually applied to materials with a small pore size and under a low suction (*e.g.*, refractories and sands), and the flow is assumed to be proportional to the suction or to be streamline.

A more general expression would be:

$$P = \frac{F}{A} \cdot \left[\frac{h}{s}\right]^n,$$

where $n = 1{\cdot}0$ if the flow is streamline, or $0{\cdot}5$ if it is fully turbulent. In the critical range it will fall between these values.

For convenience, the flow is expressed in cubic feet per minute at 60° F. and 30 in. of Hg, $h$ is in inches, $A$ in square feet, and $s$ in inches water gauge. Calculations of the Reynolds number for typical sinter mixes showed that the flow was likely to be in the transitional range, so that empirical determinations are essential.

### Determination of '$n$'

*Relation Between Air Flow and Suction*—For a given sinter bed of fixed height, the air flow per square foot will depend on the suction applied. Many experiments were carried out on sinter mixes before and after ignition to determine the relation between air flow

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Mr. Voice, until recently Head of the Field Trials Section of the Iron Making Division of B.I.S.R.A., is now Acting Director of the Central Research Establishment II of the National Coal Board; Mr. Brooks is a member of the Research and Development Department of the United Steel Companies, Ltd.; and Dr. Gledhill is at the North-East Coast Laboratory of the Iron Making Division of B.I.S.R.A.

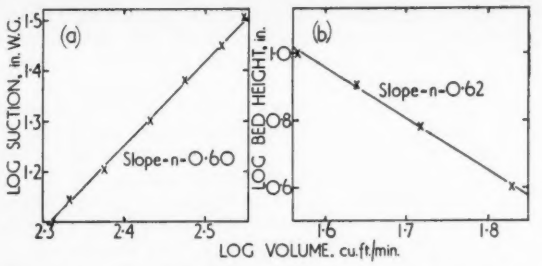



**Fig. 1—Relationship between air flow and (*a*) suction, (*b*) bed height**

and suction. Figure 1*a* shows a typical result, from which $n = 0{\cdot}60$. Results show that $n$ varies slightly for different materials and according to the state of the sintering process, and average values are as follows:

| | |
|---|---|
| Before ignition | $n = 0{\cdot}60$ |
| Immediately after ignition | $n = 0{\cdot}65$ |
| Average during sintering | $n = 0{\cdot}60$ |
| After complete sintering | $n = 0{\cdot}55$ |

To maintain constant permeability during the tests, the suctions used were limited, to avoid the danger of the bed settling and packing under extreme suction.

*Relation Between Air Flow and Bed Height*—Standard sinter mixtures were loaded to different depths into a laboratory sinter pan. A fixed suction was applied, and the air flow per square foot was measured for each different height of bed. Figure 1*b* shows a typical result, from which $n$ is found to be $0{\cdot}62$.

*Reasonable Value for* ' n '—The value for $n$ varies slightly with the type of raw material and the state of the sintering process. However, a reasonable value is $0{\cdot}60$, and this can be applied until the mixture is fully sintered.

*Standard Permeabilities*—Three values of permeability are considered:

(i) Permeability before ignition (' pre-ignition permeability ')
(ii) Minimum permeability after ignition (' trough permeability ')
(iii) Average permeability for the strand up to and including the hottest wind box (' average permeability ').

In all cases, the pre-ignition bed height is used in the calculations.

The variation of permeability as sintering proceeds is dependent on the composition of the raw mix, but, in general, the permeability drops after ignition and then rises, possibly rapidly, to a maximum value when sintering is complete.

Only the pre-ignition permeability can be regarded as a precise measure; permeabilities measured later in the process must be regarded as ' effective ' permeabilities, since the process is complex and involves the evaporation and condensation of moisture, calcination of the ore, and the combustion of the coke with resultant slag formation.

These factors are important because they limit the actual sinter rate attainable for a given fan power. The numerical value of $P$ would be altered if the bed height were expressed in feet or millimetres, or if a different value of $n$ were used. For convenience, when using the dimensions defined above and when $n = 0{\cdot}60$, $P$ is expressed in British Permeability Units (B.P.U.).

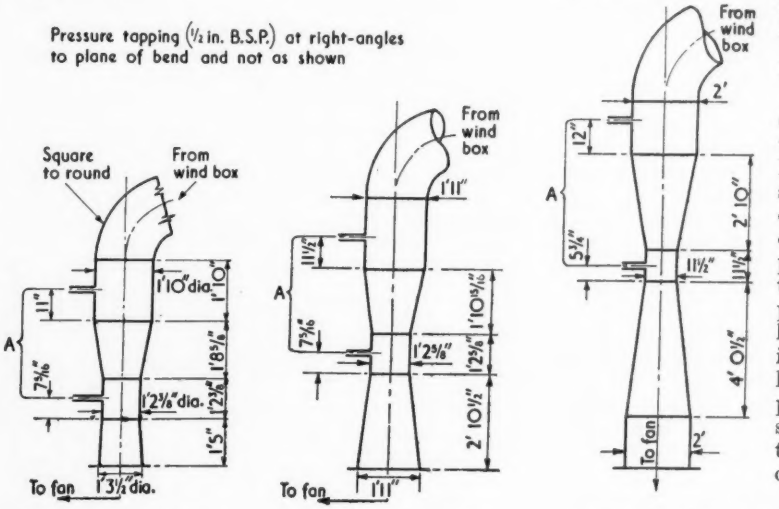
## MEASUREMENT OF PERMEABILITY

To know the permeability, the volume of air passing through a part or the whole of the sinter bed, the dimensions of that part of the bed, and the suction under the bed must all be determined. Indicating or recording suction gauges are readily available and the dimensions are easily measured. The air flow can be measured in several ways, the final choice being influenced by the type of sinter machine.

### Dwight-Lloyd-type Machines

There are normally a number of wind-legs connecting the windboxes to the main air duct. If these wind-legs are round in section, a pitot traverse can be carried out; a single position can usually be chosen for the pitot to give reliable information on the amount of air passing. Square-section wind-legs are more troublesome, but, in both cases, the pitot tube has limitations. If it is left in position for long periods, it suffers considerable damage through abrasion and produces only a low differential pressure.

A good method is to replace one or more wind-legs by Venturi-shaped circular pipes. A suitable recording pressure gauge can then be connected




(*a*) 5930 cu. ft./min. at 2 in. W.G. differential at *A* Main condition: 28 in. Hg and 100° C.

(*b*) 6100 cu. ft./min. at 2 in. W.G. differential at *A* Main condition: 28 in. Hg and 100° C.

(*c*) 4000 cu. ft./min. at 2 in. W.G. differential at *A* Main condition: 28 in. Hg and 80° C.

**Fig. 2—Venturis for use on Dwight-Lloyd machines**

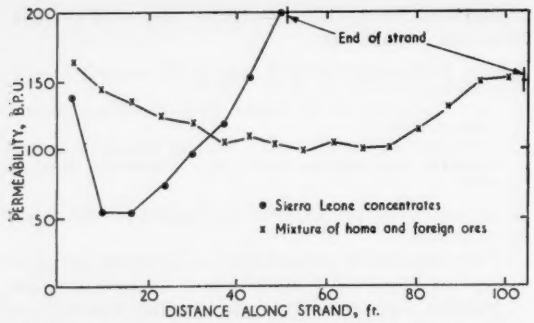



**Fig. 3—Variation of permeability along the strand**

across the Venturi throat. The permanent pressure drop through the Venturi can be made very low (less than $\frac{1}{4}$ in. W.G.), and the throat-pressure differential is about 2 in. W.G. Venturis are preferable to orifice plates, owing to the high pressure drop and the susceptibility to dust deposition and abrasion of the latter. Figure 2 shows the dimensions of three Venturis that have been used.

When calibrated (by calculation, or by model experiments if absolute accuracy is required), the air flow through the wind-leg is readily calculable in terms of pressure drop across the Venturi throat.

On a strand-type machine it is usually impossible to measure the pre-ignition permeability, but a Venturi sited 20–40% along the strand enables the trough permeability to be measured. Venturis or pitot tubes at several wind-legs up to the hottest wind-box and waste-gas temperatures are needed to calculate the average permeability. Figure 3 shows the variation of permeability along the strand observed on a Dwight-Lloyd machine, using Sierra Leone concentrates and a mixture of home and foreign ores.

### Greenawalt-type Machines

The air flow through the bed varies during the sintering process, and Fig. 4 shows the variation of permeability with time after ignition. A Venturi in the main duct is suitable for measuring air flows, or pitot traverses can be made across the duct to calibrate the trunnions or cyclones in terms of air flow and pressure drop. Readings of the air flow can then be taken or recorded and, with reference to the state of sintering, all three permeabilities can be calculated, provided that the air flow can be corrected for temperature. Figure 5 shows the alternative arrangements.

### Calculation of Permeability

When a Venturi is installed, and a suction gauge and an air-flow gauge are set up within sight of the operator, he can read off the permeability by reference to tables or graphs, or by using a slide rule modified to afford easy calculation. The trough permeability probably has the greatest effect on sinter production, because it is applicable for an important and sometimes large portion of the strand when sintering is taking place. Fortunately, the waste-gas temperature here is usually fairly constant at about 80° C., so that a fixed temperature correction can be incorporated in the devices for calculating permeability.

A prototype meter is being constructed which incorporates a suction gauge and an air-flow meter, with manual controls that can be set for bed height and $n$, so that the meter will indicate or record permeability. If this is connected to a Venturi wind-leg 20–40% along the strand, it will record the trough permeability continuously, and the operator will know the effect on permeability of any change he makes. If such a meter is installed on a Greenawalt type, the initial and trough permeabilities can be read off and the average permeability calculated from the record.

## TYPICAL PERMEABILITY VALUES

The following tables show that the permeability of a sinter mix depends on the type of ore used. For each mix, there is an optimum moisture content for maximum permeability. These figures are results obtained from experiments carried out on a laboratory sinter unit; owing to the method of filling, they are lower than results obtained on production plants.

*(a) Various Sinter Mixes*

| | Permeability, B.P.U. | | |
|---|---|---|---|
| | Pre-ignition | Trough | Av. |
| Northants ores | 130 | 90 | 110 |
| Ouenza | 165 | 80 | 95 |
| Cleveland | 135 | 75 | 80 |
| Sierra Leone conc. | 55 | 35 | 60 |
| Grangesberg | 50 | 30 | 55 |

*(b) Sinter Mixture Constant, Different Moisture Content*

| | Permeability, B.P.U. | | |
|---|---|---|---|
| Water Content, % | Pre-Ignition | Trough | Av. |
| *Home Ores* | | | |
| 14 | 76 | 54 | 71 |
| 16 | 98 | 64 | 92 |
| 18 | 127 | 90 | 113 |
| 20 | 114 | 77 | 102 |
| *Swedish Ores* | | | |
| 5 | 47 | ... | ... |
| 6 | 49 | ... | ... |
| 7 | 50 | ... | ... |
| 8 | 54 | ... | ... |
| 9 | 45 | ... | ... |
| 10 | 28 | ... | ... |

## ADVANTAGES TO SINTER-PLANT OPERATORS AND MANAGEMENTS

### Operators

The addition of water is left to the operator, who can only judge its effect indirectly on the whole sinter process. A dry mixture will take a long time to sinter, and the process can be speeded up by adding water up to an optimum amount.

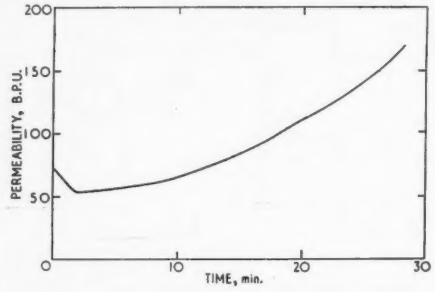



**Fig. 4—Variation of permeability with time after ignition**

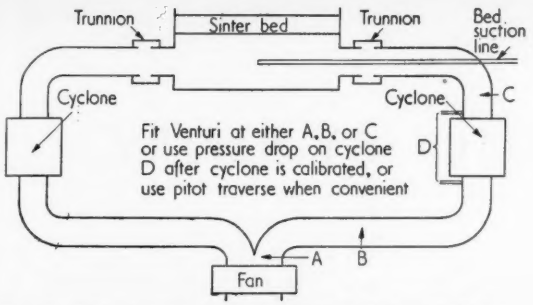



**Fig. 5—Measurement of air flow on Greenawalt-type machine**

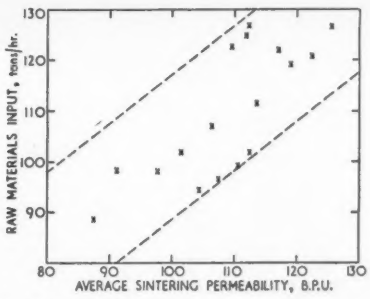



**Fig. 6—Relationship between permeability and materials input**

Hitherto, the general attitude has been that optimum bed permeability would only be possible if a perfect moisture indicator were available. By using a permeability meter, a much more realistic approach is possible. Since the optimum moisture content is not yet known, and, in any case, varies widely with any variation of the raw materials, water is added to attain the desired high or optimum bed permeability for the materials actually in use.

### Managements

Using an indicating or recording permeability meter gives the management a valuable method of assessing all plant variables. The plant can be modified stage by stage, and the effect on permeability measured.

Different types of mixing (*e.g.*, drum or pug mill, fine or coarse water spray, etc.) can be tried, and the effect on bed permeability assessed.

The degree of tertiary crushing or the size of raw materials can be changed and the effect assessed. A monetary value can then be given to the crushing process in terms of increased bed permeability and sinter output. It can be shown whether or not, for a particular practice, it is economical to crush the return sinter.

Details of the swinging spout or roller feed can be altered (*e.g.*, the angle of the back plate and height of fall of material), so as to prove whether these details are critical for the material being sintered or not. If they are important, the optimum settings can be found.

The effect of returned sinter on the characteristics of the bed can be determined and its proportion fixed at the minimum required to give a sufficiently strong sinter and a high permeability. The effect of other constituents can be similarly examined.

## FURTHER DEVELOPMENT

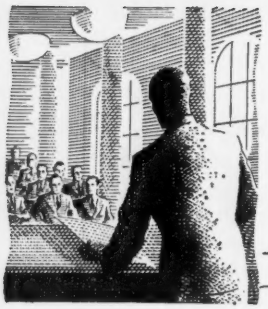
It should be possible to make the permeability meter control the water addition so as to maintain a high or optimum trough permeability. Using the permeability information, it is possible to separate the physical and chemical or ignition problems associated; for instance, laboratory experiments suggest that lime additions to Sierra Leone concentrates decrease the time needed to sinter. During each experiment, the bed permeabilities and the air requirement per ton of raw materials were measured. The lime additions did not appreciably affect the bed permeabilities, but they greatly reduced the amount of air required. For this reason, increased sinter output is possible on a given plant with a fixed fan horsepower. Any change in balling up, water control, etc., that increases the bed permeability should increase sinter output still further.

The permeabilities should be determined on all sinter plants and ways of increasing them investigated. Large increases in permeabilities have been attained at one plant, with corresponding increase in sinter production. Figure 6 shows that the tonnage input on to the strand is related to permeability, despite changes in the bed height, material mix, and number of windboxes used. All the sinter made was found to be acceptable by the blast-furnace.

The permeability equation enables the effect of various operating conditions on sinter output and power consumption to be assessed, and is of particular importance when designing new sinter plants.

## Acknowledgments

The arguments developed in this paper arose from recent work concerned with assessing the capacity and performance of sintering plants, and the authors are indebted to the United Steel Companies, Ltd., for enabling them to make use of experience and data gained during large-scale trials at the works of the Appleby-Frodingham Steel Company. Their thanks are also due to the Sintering Sub-Committee of the British Iron and Steel Research Association, for permission to publish this paper.



# DISCUSSION ON PAPERS

DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

## Correspondence on the Paper—

## THE STRESS-CORROSION CRACKING OF MILD STEELS IN NITRATE SOLUTION*

*By R. N. Parkins*

Monsieur **E. Herzog** (S.A. des Hauts-Fourneaux, Forges et Aciéries de Pompey) wrote: Dr. Parkins has undertaken the study of a very complex problem, starting from new ideas and using new techniques, such as X-rays. His experiments show clearly the important part played by iron carbide in the phenomena of intercrystalline corrosion of steels under stress in nitrate solution. This conclusion is in good agreement with some previously published results. In collaboration with Professor A. Portevin, I attributed an essential rôle to the presence of carbon in the steel.[1] The principal conclusion of this first investigation was as follows:

" In the case of mild steels, dissolution and precipitation of phases is, it seems, related to the propagation of intercrystalline corrosion. In fact, a low chromium–aluminium steel that does not harden by quenching does not crack whatever thermal treatment it receives. On the other hand, a nickel steel that has been entirely or partially quenched cracks rapidly, whereas one in the normalized (annealed) state cracks only after long periods (1600 hr.).

The same conclusion was reached with a mild steel containing carbon with small additions of Cr and Si (0·2%)."

In the same study, we showed the accelerating effect of heating to 700° C., followed by rapid cooling (air or water), for steels (" Izzett ") that contained 0·14% of C and were thoroughly killed; these steels are usually very stable in the normalized state at the $Ac_3$ point (900° C.). With a killed basic O.H. steel containing Al and Ti and 0·06% of C we obtained quick fractures even after normalization at 900° C.

Later, we still insisted on the importance of the part played by the carbon, whose tendency to pass into solid solution and then to precipitate must be reduced as far as possible.

The conclusions of the paper published in *Metaux et Corrosion*[2] in 1949 and our communication to the Journées de Corrosion in 1947 are as follows:

" We have seen that the combination of small chromium and aluminium contents (2 : 1) for a restricted carbon content ($\leqslant$ 0·13) leads, after rolling, to a steel that withstands intercrystalline corrosion by nitrates, even when subjected to a static stress of nine-tenths of the ultimate stress (tests by bending under constant load). This resistance is unaffected by thermal treatments (quenching and over-heating) between the transformation temperatures (Ac and Ar) and also by cold-working.

A considerable decarburization at about 1100° C., followed by an increase in grain size, reduces by 75% this resistance to corrosion under stress by nitrates.

In the same way, the grain boundaries resulting from solidification are very susceptible to this type of attack. In these steels, the entry of carbides into solid solution is slow and relatively slight, as is shown by the results obtained from the Chevenard differential dilatometer and from microtensile tests.

It therefore seems that a high resistance to intercrystalline corrosion is obtained in the presence of very stable carbides, only slightly or slowly soluble in solid solutions of $\alpha$ and $\gamma$ iron.

Another factor of prime importance is demonstrated by these tests: the conditions of formation of the boundaries between the grains. The results obtained lead to the conclusion that submicroscopic voids, which separate the grains, enlarge the paths by which the corrosive liquid penetrates into the interior of the crystal structure, especially under the influence of stress pulling the grains apart."

The addition of a considerable amount of Al (say, 0·7–1%) modifies the transformation diagrams for steels containing about 0·10–0·12% of carbon; a mild steel with this Al content tends to eject iron carbide between the grain boundaries. The diffusion of carbides is rapid, and in the presence of $O_2$ and $CO_2$ superficial decarburization takes place very rapidly. When these steels have surfaces free from carbides, with very large grains, they are still liable to stress-corrosion cracking. In the presence of an element that fixes the carbon, such as chromium, decarburization and grain-coarsening are limited to thin superficial layers. These steels, with less than 0·13% of C, 2–4% of Cr, and about 0·7–1% of Al, are very resistant to stress-corrosion cracking in nitrates and in caustic soda, whether or not they are quenched, over-heated, or cold-worked. They are hardened completely (martensite–bainite with U.T.S. = 100–120 kg./

* *J. Iron Steel Inst.*, 1952, vol. 172, pp. 149–162.

## Table I

### INTERGRANULAR CORROSION OF DIFFERENT STEELS IN NITRATE SOLUTIONS AND IN HYDROGEN SULPHIDE

**Jones tests on samples 3 mm. thick, normalized at 20° C. above $Ac_3$. These tests cause a maximum deformation of 9%, and the stress applied in the exterior layers exceeds the initial elastic limit of the sample (as normalized)**

| Steel | Composition | | | | | | | | | Life, hr. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 57% Calcium Nitrate, 3% Ammonium Nitrate, at 110–120° C. | | Hydrogen Sulphide at 1 atm. and 15–20° C. | |
| | C, % | Mn, % | S, % | P, % | N, % | Si, % | Al, % | Cr, % | Mo, % | Cracked | Not Cracked | Cracked | Not Cracked |
| Rimmed B.O.H. mild steel | 0·07 | 0·36 | 0·018 | 0·020 | 0·006 | Trace | ... | 0·065 | ... | 16–24 | | | 3000 |
| Rimmed Thomas mild steel | 0·05 | 0·39 | 0·032 | 0·056 | 0·016 | ... | ... | 0·02 | ... | 8–12 | | | 3000 |
| Killed B.O.H. mild steel | 0·08 | 0·32 | 0·024 | 0·026 | 0·008 | 0·09 | 0·06 | 0·07 | ... | 48–72 | | | 3000 |
| N 80 | 0·37 | 1·80 | 0·011 | 0·026 | 0·015 | 0·12 | ... | 0·035 | 0·30 | 24–48 | | 15–48 | |
| APS 20 | 0·13 | 0·50 | 0·014 | 0·024 | 0·014 | 0·40 | 0·78 | 3·95 | ... | | 3000 | | 3000 |
| | 0·37 | 0·38 | 0·020 | 0·028 | 0·010 | 0·30 | 1·30 | 3·70 | ... | 50–70 | | 50 | |

sq. mm.) only by hyperquenching after torch welding (fusion under argon, for example), which leaves residual stresses in the lattice, making these steels liable to cracking. A further annealing at 650° C. restores their stability. Martensite or bainite and their neighbouring states (heated to below 600° C.) are structures that are liable to this type of corrosion.

On this subject, the work of Houdremont, Benneck, and Wentrup[3] has clearly shown that the structures which are liable to stress-corrosion cracking in nitrates are martensite and its decomposition products as far as 500° C. at least. It is only after tempering to 600° C. that carbon or low-alloyed steels become stable when starting from a quenched state.

Welds include zones where the carbon remains in supersaturated solid solution on air-cooling, or where it remains insufficiently decomposed. For this reason, Dr. Parkins has found that reheating of welds to between 350° and 650° C. renders mild steels stable after welding, either by release of the residual stresses or by the complete decomposition of the unstable substances (*e.g.*, martensite).

### Effect of Removal of Carbon by Hydrogen

The experiments carried out by the author at about 730° C. are very informative, as they show that with a minimum carbon content (less than 0·016%) the tendency to form cracks is non-existent or very small.

Our own trials were carried out at 1000° C., and showed an activating effect for rimmed mild steel and for very stable steels containing Al and Cr, with about 0·02% of C in the decarburized layers.

At high temperatures the grain is coarsened by the removal of carbon and the new grain boundaries are more readily attacked than the former ones. This may be explained by Professor Benedick's hypothesis that wetting is facilitated by capillarity or increased porosity, and possibly also by diffusion in the vacant regions surrounding the grains, in accordance with the suggestion of Professor J. H. Greenwood.[4]

### Effect of Heating to 700° C.

At the transformation point, 700° C., the carbon begins to dissolve in the ferrite.

Dr. Parkins' tests show the effect of cementite. May I ask him whether his samples were slowly or quickly cooled, whether he carried out tensile tests, and whether he obtained a sharp break in the stress/strain diagram at the elastic limit ?

This detail is important, because a small break in the curve, or no break at all, shows the presence of carbon dissolved in ferrite, and dissolved carbon tends to be precipitated along the grain boundaries (especially at 100° C.), which leads to an increased tendency to intergranular stress-corrosion. Thus, globular pearlite and a ferrite supersaturated with carbon exist together at 700° C., the latter decomposing under the influence of slipping (or stresses) at the surrounding temperature or at a slightly higher temperature.

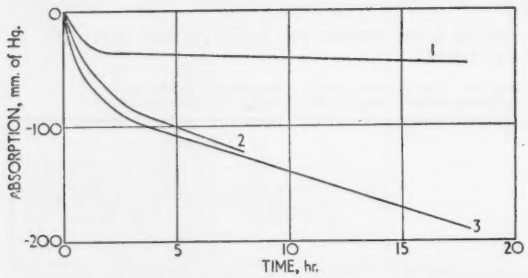
### Action of Gases containing Hydrogen Sulphide

The fractures reported in Dr. Parkins' paper when welds were exposed to the crude gas from coke ovens or from gas generators are perhaps connected with gaseous impurities such as hydrogen sulphide, sulpho-cyanides, and cyanides, and with the humidity of these gases, as all these constituents favour intergranular attack under stress.

In the gas from oil wells, $H_2S$ is a dangerous impurity which, if it exceeds 10% of the gas, can cause rapid fractures. Intergranular corrosion in washing columns under a gas pressure of 25 kg./sq. cm. in coke ovens has been observed by the Belgian Nitrogen Company at Marly.

We have compared the actions of wet $H_2S$ and nitrates. There are certainly some similarities, but there are also important differences to be observed between their types of stress-corrosion. Unlike nitrates, $H_2S$ does not cause cracking after cold-working and ageing of killed or rimmed steels (previously normalized). The effect of nitrogen must be negligible, for even rimmed Thomas steels with 0·016% of N do not show intercrystalline attack.

After a thorough quenching at 720° C., cracks are produced and are accelerated by cold-working; quenching in water from 900° C. also produces cracks, but more slowly. In a similar manner to nitrates, $H_2S$ produces *very rapid* cracking in carbon or low-alloyed steels with martensitic structure, more or less decomposed (between 300° and 500° C.). Table I gives the corrosion rates for steels in nitrates and in hydrogen sulphide.




Curve 1. Heat No. 8.133. *DOM*. Extra-mild rimmed steel, normalized for 30 min. at 920° C. and air-cooled. Composition: 0·07% C, 0·36% Mn, 0·020% P, 0·018% S. Yield stress = 31·6 kg./sq. mm.; U.T.S. = 43·8 kg./sq. mm.; El = 32·6%. Not cracked after 3000 hr., under load greater than 32 kg./sq. mm.

Curve 2. Heat No. 63.126. *PM* 30. Semi-hard Mn–Mo steel (grade N80), normalized at 830° C. Composition: 0·37% C, 1·80% Mn, 0·12% Si, 0·026% P, 0·010% S, 0·30% Mo. Yield stress = 73·1 kg./sq. mm.; U.T.S. = 115·1 kg./sq. mm.; El = 14·9%. Cracked after 24–48 hr., under load of 65 kg./sq. mm.

Curve 3. As for curve 2, but after 10% reduction (by cold rolling)

**Fig. 1—Absorption of hydrogen by reaction between hydrogen sulphide (at 20° C.) and different steels**

Sorbite gives a certain stability, but cold-working again leads to a risk of cracking under stress. In the same way, the intermediate products of the transformation, such as bainite, and austenite untransformed but enriched in carbon, are very sensitive to $H_2S$ and to stresses equal to or greater than the elastic limit.

Hydrogen sulphide does not attack carbides, but a couple is formed between $Fe_3C$ and ferrite. One special factor is then determinant: the rate of absorption of atomic hydrogen. Figure 1 shows examples of a steel liable to cracking, with rapid absorption of hydrogen (curves 2 and 3), and a steel not liable to attack, with slow absorption of hydrogen (curve 1).

These trials show that in the two cases of stress-corrosion cracking, one in an oxidizing and the other in a reducing medium, carbon in solid solution or unstable phases leads to conditions that are very conducive to this type of corrosion.

The investigations carried out by Vollmer, Rees, and others[5–7] show clearly the rapid fractures of martensitic steels in $H_2S$.

Dr. Parkins' conclusion about the part played by carbon in corrosion phenomena in steels under stress, unalloyed or only slightly alloyed, is well confirmed by numerous experimental observations. The effect of internal residual stresses cannot be neglected, and it is essential to seek means of preventing these stresses completely.

The merit of Dr. Parkins' paper is that it gives evidence that a quite stable structure constituted by grain-boundary cementite and ferrite (softened entirely) can generate intergranular stress-corrosion cracking. On the other hand, we know that ' unstable structures,' such as martensite and carbon-saturated ferrite prone to carbide precipitation on grain boundaries under stress, are not safe. Thus, for aluminium-killed carbon steels, only pearlitic structures seem to be resistant to this kind of corrosion.

## AUTHOR'S REPLY

Dr. **R. N. Parkins** (University of Durham, Newcastle-upon-Tyne) wrote in reply: The influence of the carbon content on the intercrystalline corrosion of mild steels has been observed by a number of workers, as acknowledged in the text of the paper. Previously, however, either the result has been ignored or an explanation has been offered on the basis that the carbon forms an unstable phase which is anodic to the remainder of the structure. It is inferred from M. Herzog's discussion that he favours such an explanation. Although this mechanism has much to commend it and is, of course, the basis of most theories of stress-corrosion cracking, it is difficult to see how such an explanation can hold for mild steels as opposed to low- or high-alloy steels.

Thus, the suggestion of M. Herzog, that a reason for the disappearance of susceptibility to intercrystalline corrosion in welded plates after annealing at temperatures of the order of 350° C. is the complete decomposition of martensite formed during welding, is not in agreement with the observed facts. If the susceptibility of welded structures were due to the presence of martensite, it would be expected that the higher the carbon content the more readily would failure occur, because of the greater facility for martensite formation with increasing carbon content. This expectation is the opposite of what is actually observed. Furthermore, some experiments were carried out for the purpose of determining the degree of stress relief at the low temperatures used, and these indicated a sufficient lowering of the stresses in the plates to account for the disappearance of susceptibility.

In addition, it is difficult to imagine the formation of martensite in any of the samples on which heat treatments were performed in the present work, as in all cases cooling was carried out in the furnace, occupying a period of 4–5 hr. No tensile tests were carried out on these heat-treated specimens.

The suggestion that prolonged annealing results in the collection of vacant lattice sites in the grain boundaries—as observed by Greenwood—and thereby causes increased susceptibility may well be true, since, in addition to facilitating wetting, such sub-microscopic voids must increase the degree of disorder in boundary regions beyond that arising from other sources.

It is almost certainly correct that cracking of gas mains is connected with gaseous impurities in the condensate, but it is doubtful whether any simple explanation on the basis of hydrogen sulphide or cyanides can be accepted, because, according to the literature, these solutions give rise not to intergranular but to essentially transgranular cracks.

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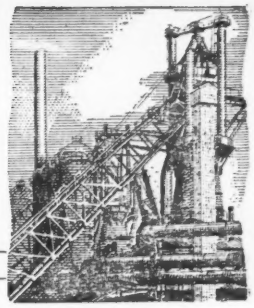

# Relining and Enlarging No. 9 Blast-Furnace at Appleby-Frodingham

*By G. D. Elliot, A. Bridge, E. Jarvis, and T. E. Mitchell*

SYNOPSIS

Number 9 blast-furnace at the Appleby-Frodingham Steel Company's works at Scunthorpe was completely relined in 1952 in a total time of 23 days. A description of the job is given, together with some details of methods, tools, gear, etc. 762

THE Appleby-Frodingham Steel Company has for several years devoted much attention to relining and repairing blast-furnaces in the shortest possible time. In these days of pig-iron shortage, the need for doing so is only too obvious. A list of recent relining and repair performances at Appleby-Frodingham is given in Table I. For obvious reasons, times are not given for the four small old furnaces.

In September, 1952, it became necessary to reline No. 9 furnace and to enlarge its hearth diameter from 22 ft. 0 in. to 25 ft. 0 in. As a result of the Company's long experience, combined with good fortune, the job was accomplished in 22 days 23 hr. 30 min. from blast-off to blast-on. This is believed to be the fastest time yet achieved for relining a large blast-furnace.

The Company is favourably situated in that it has both plate and section mills, together with a fairly large structural steel organization. These factors are obviously of value in achieving good relining performances. Nevertheless, the authors believe that many of the lessons learnt are applicable to less extensive plants.

Although the paper describes a particular operation, it should be emphasized that the general plan and methods described were applied to all the operations listed in Table I. When the first attempt at repairing quickly was made in 1944 (No. 10 hearth repair), it was described in the works as a 'Combined Operation.' The job described in this paper is known as 'Combined Operation No. 12.'

## GENERAL ORGANIZATION

The time occupied in relining a blast-furnace is largely decided by the amount of thought and preparation given to it beforehand. The duration of the next relining is, in fact, decided by the thought put into the current relining. On all the jobs listed in Table I, a day-by-day diary was kept, which proved to be of great value in each subsequent relining; each diary set the pace for the next job.

From the day a blast-furnace blows in, it is known that one day it will have to be relined. A few people in the general works organization never forget this fact. Some months before the furnace is due to be relined, one or two people have drawn up a time-and-job schedule, which is always based on the day-by-day diary of the previous relining. By this time, all the essential materials have been ordered. A relining starts two or three years before the furnace is blown out.

After the time-and-job schedule has been agreed by the administrative heads of the departments concerned, a meeting of foremen and section leaders is called. At this meeting, the whole job is explained and the schedule is agreed by everybody concerned. Any modification, whether up or down in time, that is suggested by a foreman is incorporated in the schedule, which is then circulated to all the foremen and section leaders involved. Figure 1 shows the time-and-job schedule agreed in this way for the relining that is to be described, and also the actual times taken for the various jobs estimated in the time-and-job schedule. This shows that when the 'pacemaker' jobs were done in less than estimated time, the subsidiary jobs fell into line.

## TOOLS AND TACKLE

Relining a blast-furnace is a job which calls for methods, tools, and tackle that are not usual in day-

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Mr. Elliot is Works Manager (Iron), Mr. Bridge is Chief Ironworks Engineer, Mr. Jarvis is Assistant Plant Engineer (South Ironworks), and Mr. Mitchell is Blast-Furnace Manager (South Ironworks), all with the Appleby-Frodingham Steel Company.

(a) Estimated Times
(b) Actual Times
SEPTEMBER
OCTOBER
Previous week
Week one
Week two
Week three
Blowing-out = day 1
Wind-off to wind-on: estimated time 35 days
Blowing-in = day 36
Wind-off to wind-on: 23 days
Blowing-in = day 24
Preparations for blowing-out
Blowing-out
Cooling down
Raking out to tuyere level
Felling lining of stack & bosh
Demolition of hearth & bear
Clean out stove flue
Clean out dustcatchers & dirty-gas main
Warm up stoves & dry furnace
Provision of materials for kindling, etc.
Filling furnace
Blowing-in
Dismantling gooseneck
Dismantle & overhaul clay gun
Dismantle, overhaul, & re-erect pipework
Cleaning & painting hoist & furnace top
Fix furnace lubrication around top
Dismantle bell & hoppers, etc.
Fix swinging stage for felling lining
Overhaul of bleck engine & pulleys, etc.
Fix door for bleck engine & stage
Overhaul of furnace & stage
Cleaning out water mains & drains
Fix & pack gland ring between tuyere belt, bosh
Re-erection of bell & hoppers, etc.
Modify & re-erect gooseneck, etc.
Re-erection of clay gun
Erection of bosh tuyeres
Modify skips for brick handling
Erect brick trolley platform at hoist foot
Burn access window in hearth jacket
Dismantle existing bosh jacket & tuyere belt
Fix blasting cover over hearth jacket
Erect top superstructure (reline rig)
Erect stage at linnel level
Erect new bosh jacket & tuyere belt
Remove blasting cover
Blank window in hearth jacket
Remove swinging stage & linnel stage
Dismantle top superstructure
Fix circular & radial troughs to hearth jacket
Reconvert charging skips to normal
Steelworks for third slag notch
Modify slag-dock railways (temporary)
Repair coke bunker linings (gunite)
Pour refractory concrete hearth base)
Pour refractory concrete (throat armour)
Repair iron & slag dock railways
Repair horse-shoe & H.B. mains, etc.
Repair stoves & downcomers, etc.
Building stack brickwork
Building hearth bottom
Building crown brickwork (refractory concrete)
Building hearth brickwork
Building bosh brickwork
Rebuilding iron runners & slag falls
Department concerned
Engineers
Mechanical Department
Production Department
Construction Department
Civil Engineers
Bricklayers

Fig. 1—Estimated time-and-job schedule, and actual time taken

to-day blast-furnace operation. The Company has accumulated a large amount of relining gear over a long period, and this is collected and put into good order during the few weeks before a relining. Most of the gear now held by the Company for relining is listed in Table II. It includes many items of use in day-to-day maintenance and in the numerous unusual breakdown jobs that occur from time to time in any large iron and steel works, but it by no means covers all the gear used in relining ; obviously, much ' routine ' gear is used.

## PREPARATION

During 1950, it was decided that when No. 9 furnace was relined, its hearth diameter would be enlarged to 25 ft. Design work was then executed to determine what was needed, and all necessary materials were ordered. These preparations may be described as ' long-term.' Bricks, bell, gooseneck saddles, bosh steelwork, coolers, etc., were all ordered at this time. Figure 2 shows the agreed general design of the furnace. The principal differences were enlargement to 25 ft. hearth diameter and from 35,630 to 39,920 cu. ft. working volume. It was also decided to revert to the old practice of using spray-cooled hearth and bosh jackets instead of stave coolers and copper plates. These changes, together with the use of thinner carbon linings, were in fact the only things that made the enlargement of the furnace possible.

Similarly, plans were made for carrying out the job, *i.e.*, tapping the bear, handling bricks, etc. This meant that many foremen had to think ahead, and that many plans were made, considered, rejected, and remade before the final plan emerged.

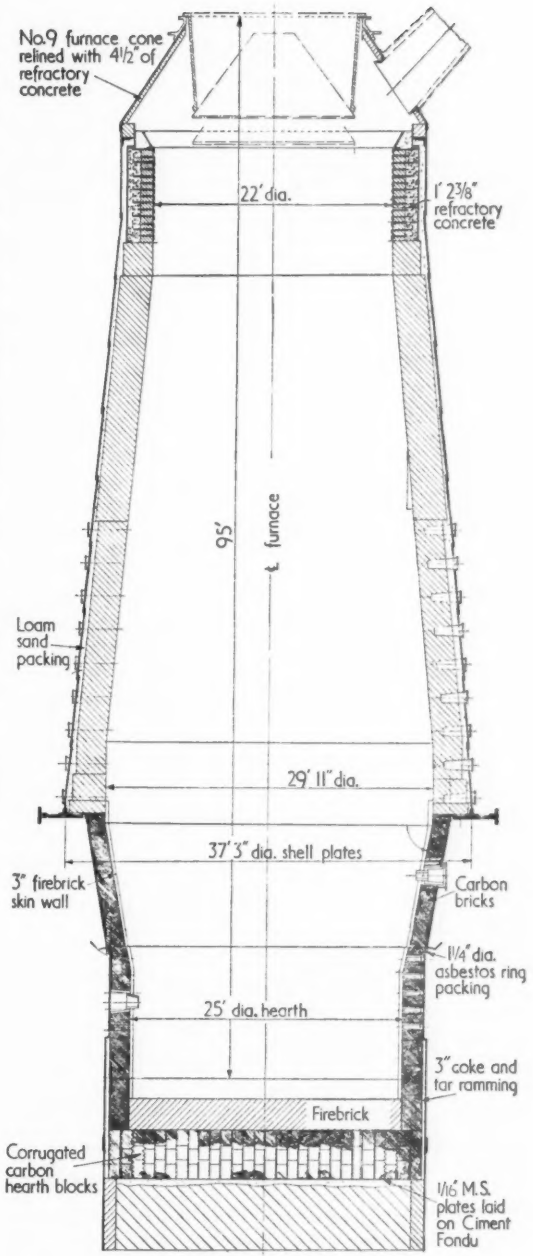
On 15th September, 1952, the ironworks department was asked how soon it could blow out No. 9 furnace and implement the relining plan. At this time, the furnace was making an average of 3750 tons/week, more than ever before in its history. Twenty-four hours later, the blowing-out date was fixed at 27th September, 1952.

### Table I

### BLAST-FURNACE REPAIR AND RELINING TIMES

| Furnace No. | Date Blown Out | Date Blown In | Days Off |
|---|---|---|---|
| 1 | 11. 8.45 | 8.10.45 | 58 |
| | 14. 9.49 | 24.10.49 | 40·5 |
| 4 | 28. 3.41 | 18.11.41 | 235 |
| | 22. 2.47 | 18. 8.47 | 177* |
| | 6. 1.51 | 1. 2.51 | 26·5† |
| 5 | 8. 4.45 | 11. 6.45 | 64 |
| | 27. 2.50 | 5. 4.50 | 36·33 |
| 6 | 2.12.42 | 16. 8.43 | 257* |
| | 15. 2.49 | 4. 4.49 | 48 |
| | 22. 4.52 | 8. 5.52 | 15·69† |
| 9 | 23.10.44 | 21.11.44 | 29‡ |
| | 2.11.46 | 16.12.46 | 44 |
| | 27. 9.52 | 20.10.52 | 22·98 |
| 10 | 8. 5.44 | 26. 6.44 | 49‡ |
| | 9. 2.46 | 13. 4.46 | 64 |
| | 25. 8.51 | 26. 9.51 | 32·49 |

* Day-work only † Stack only ‡ Hearth only




| | Area, sq. ft. | Volume, cu. ft. |
|---|---|---|
| Hearth | 490·87 | 4745 |
| Bosh | 703·30 | 7933 |
| Top | 380·13 | 4306 |
| Stack | — | 27,150 |
| Bell | 176·71 | — |

Effective volume = 39,920 cu. ft.

**Fig. 2—General design of No. 9 furnace after relining**

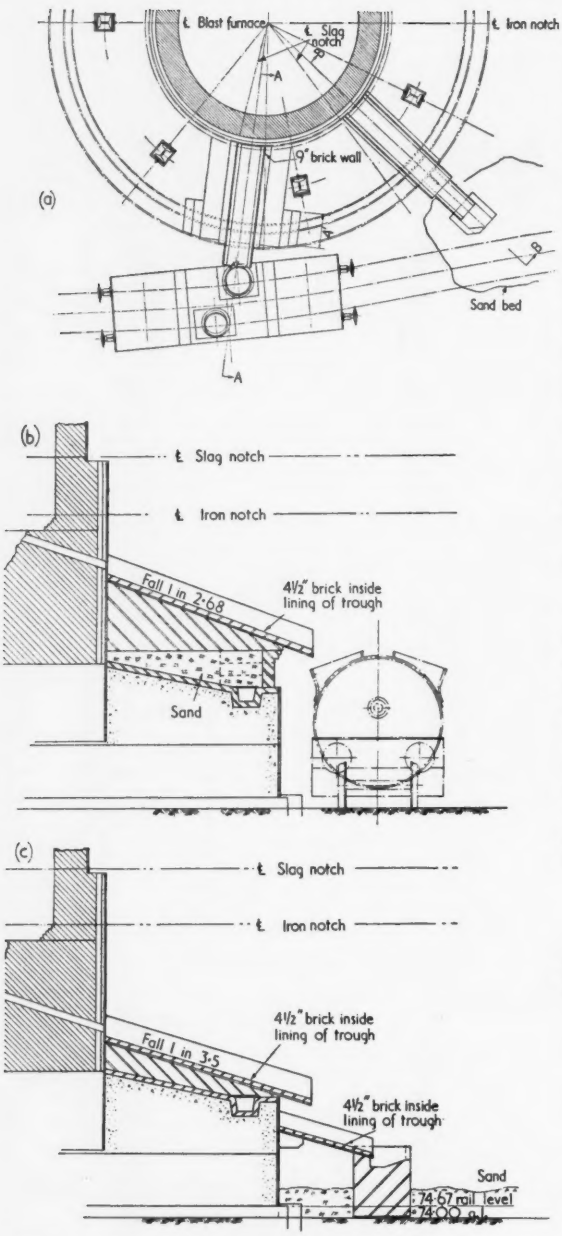



**Fig. 3—(*a*) Sectional plan view of No. 9 furnace ; (*b*) section on *AA* ; (*c*) section on *BB***

At this point, what may be termed 'short-term' preparations moved into action. Plans had been made long before ; between February and July, 1952, the following arrangements had been made, and in the 12 days left before blowing-out the necessary work was carried out.

**Preparations for Tapping the Bear**

When the furnace was relined in 1946, a special stave cooler was incorporated to permit the bear or salamander to be tapped without damage to the stave. Subsequent thought indicated the possibility of a second bear tap at a lower level, in case the first did not fully drain the furnace of iron. Runners for bear tap 1 as designed were now constructed. Bear tap 2 was designed to lead the iron to sand-beds prepared at yard level below the cast-house floor. The jury runner and necessary sand-beds were now constructed (*see* Fig. 3).

**Brick Handling**

The plan called for bricks to be unloaded from rail wagons to a wharf beside the scale-car track, whence they could be barrowed to the modified main skip for lifting to the furnace top. Steelwork for this wharf was already in existence from previous relines, and was now erected. The general arrangement of the brick-handling wharf is shown in Fig. 4.

**Oxygen and Compressed Air**

During a relining, air and oxygen are required at so many places that air and oxygen lines, connected to the normal plant lines, are set up around the cast house and up to the furnace top.

**Pipe Fitting**

It is impossible to cut all pipe lengths beforehand and it wastes time to carry pipes for cutting and screwing to a distant maintenance shop. A power saw and a screwing machine were therefore erected on the cast-house floor, as near to the furnace as possible.

**Trolley**

The 40-ton bell-lifting trolley, usually installed on the furnace top, has for many years been kept on the ground. Experience has shown that the trolley was so seldom required that, if it were left on top of the furnace, all the motions were frozen when it came to

## Table II

### PLANT, TOOLS, AND GEAR

**The Table gives a partial list of the relining tools and plant, in addition to major items mentioned in the text. Items 1–12 were used in wrecking. Drivers for items 13–17 were additional to the labour force detailed in the Appendix.**

| Item | No. | Brief Description |
|---|---|---|
| 1 | 8 | Jackhammer drills |
| 2 | 1 | Consolidated pneumatic type 375 impact wrench |
| 3 | 110 | Drill steels: Length 2–8 ft. Dia. 1⅜–1⅝ in. (all carbide-tipped) |
| 4 | 4 | 80-lb. paving breakers |
| 5 | 2 | 60-lb. paving breakers |
| 6 | 120 | Steels for paving breakers |
| 7 | 2 | 90-lb. long-stroke rivet cutters |
| 8 | 48 | Steels for rivet cutters (24 chisel end, 24 moil end) |
| 9 | 2 | 25-lb. chipping hammers |
| 10 | 48 | Steels for chipping hammers |
| 11 | 3 | Single-piston scaling hammers |
| 12 | 6 | 17-ton Duff Norton ratchet jacks |
| 13 | 1 | Muir-Hill loader (¾ cu. yd.) |
| 14 | 3 | Muir-Hill dumpers (2½ cu. yd.) |
| 15 | 1 | Aveling Barford dumper (4½ cu. yd.) |
| 16 | 3 | S.W.B. truck (4½ cu. yd.) |
| 17 | 1 | Ruston Bucyrus 10 excavator (⅝ cu. yd.) |
| 18 | 12 | Warry barrows (for brick handling) |
| 19 | 1 | Kango electric hammer (for ramming) |
| 20 | 1 | Concrete mixer (⅜ cu. yd.) |
| 21 | 3 | Clipper masonry saws |

be used. After overhaul, the trolley was lifted to its place during a furnace stoppage, when other small preparatory jobs were carried out. This indicates that it is a reasonable risk to have one trolley to each pair of furnaces.

**Brick Cutting**

Special brick shapes are much more expensive than standards, but brick cutting can be by far the most time-consuming job in building such sections as tuyere arches. Special shapes are therefore used for many jobs. When cutting is essential, as much as possible is done beforehand. For example, each tuyere arch is cut, 'shop-erected,' and match-marked, so that the whole assembly fits into square brickwork and only square cuts are necessary during actual erection. Clipper masonry saws are used for cutting, three being sited near the furnace. As bricklaying proceeds up the stack, the saws are taken to successively higher cooler platforms.

**Pebble Chute**

The standard Appleby-Frodingham method of blowing-out leaves the furnace full of pebbles. This material flows very freely, much faster than it can be handled as it accumulates on the floor. To let it do so on the cast-house floor would create a hindrance, and so before the furnace was blown out, a hole was cut through the cast-house floor to a free space below at yard level. A steel chute was prefabricated for attachment to a point on the bosh steelwork above the hole in the floor. Before blowing-out day, a second chute was erected to gather debris from the hole in the cast-house floor and lead it to a point where a $\frac{3}{8}$-cu. yd. face-shovel could load it into lorries and dumpers. Almost all the demolition material was taken from the site in road vehicles.

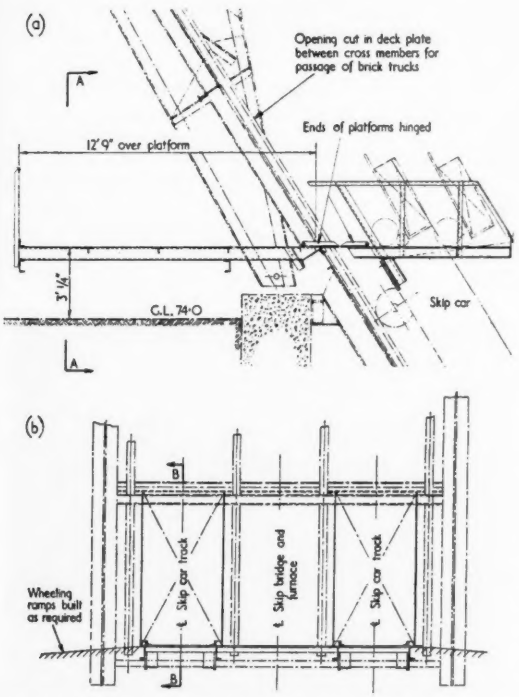



**Fig. 4—Arrangement and details of steelwork at bottom of skip bridge : (*a*) Section *BB* ; (*b*) section *AA***

**Temporary Lighting**

For fast and safe working conditions, every working space must be well illuminated. This demanded an appreciable amount of temporary lighting, which was erected before the furnace was blown out.

**Siren**

With blasting being carried out round the clock, a good warning system is vital. War-time air-raid sirens were used for this purpose. Before each single shot was fired, the siren was sounded ; the resulting explosion acted as the 'all clear.'

**Outside Help**

Although the overwhelming majority of the work was carried out by the Company's own organization, specialist help was required in four directions :

*Blasting*—For many years, great use has been made of explosives for wrecking the lining and removing the bear. The Technical Service Department of Imperial Chemical Industries, Ltd., has, since 1938, done this work for Appleby-Frodingham. It has developed special techniques and explosives, so that its part in the job has become invaluable. It is doubtful whether the use of explosives anywhere else shows such a profitable return. Arrangements were now made for two skilled operatives to come on duty two days after the furnace was to be blown out. Blasting went on round the clock, as necessary. Although preparation for blasting proceeded all the time, most of the actual shot-firing was carried out during meal-times and shift-changing periods.

*Painting*—Thomas Cotton, Ltd., of Mansfield had been given the contract for painting the whole of the furnace, stoves, dustcatcher, steelwork, etc. Arrangements were made for them to start painting as soon as the furnace was blown out.

*Cast-Iron Cutting*—The British Oxygen Company, Ltd., supply skilled operatives to carry out the rather difficult task of burning a large 'window' through the hearth jacket and stave coolers. In itself, this is not a big job, but it is important. Arrangements were now made for it to be done.

*Guniting*—During the relining period, the furnace coke bunkers were repaired and the gunite lining renewed. This work was carried out by the Cementation Company, Ltd., Doncaster.

**Staff**

For a relining to be done quickly it must be as well staffed as any production job. A production manager, two production foremen, and a foreman mechanic remained on each shift from blowing-out to blowing-in. As their work justified it, other sections, such as boilersmiths, bricklayers, and pipefitters, all covered each shift with supervision of at least foreman standard. Supervising the whole job were the plant manager and plant engineer, who were relieved of all routine duties for the period of the reline.

**General Catalogue of Work to be Done**

This is shown concisely in Fig. 1. On the seventh day of the relining, it was decided to install a third

slag notch on the furnace, complete with a new runner, which delivered the slag through a hole in the cast-house floor to slag ladles on the service track. This meant hurried design and fabrication of the necessary materials.

Very few of the jobs listed were solely the concern of one department or group ; every job had to be tied in with other jobs, and this tying-in of hour-by-hour organization needed rigorous supervision. Two or three different groups often had work to do in the same confined area ; it was then the duty of the supervisor to decide priorities. A copy of the time-and-job schedule was issued to each supervisor for his information. With it he could see each day whether his section of the work was behind or in front of the constantly altering timetable.

## BLOWING-OUT AND RELINING THE FURNACE

No blast-furnaceman is happy about blowing-out a furnace ; the history of the trade is filled with too many cases where serious accidents have occurred. After much thought and experiment, Appleby-Frodingham has adopted a method of blowing-out that is believed to be safer than any other method so far practised. In developing this method, it was very desirable to achieve rapid emptying of the furnace once it had cooled down. For this reason, quartzite pebbles screened at 1–2 in. were used. Water meters were fitted because a knowledge of how much water can be added and how quickly the water flow can be increased has been gained from previous relinings.

On Friday, 26th September, 1952, the furnace was taken off-wind for two hours to make final preparations for blowing-out. During this stoppage, the bell-changing trolley, which had been put into good condition, was hoisted into place on the furnace top. All the bosh tuyeres were closed and the furnace was isolated from the gas main. So many troubles can occur during blowing-out that it has long been considered worthwhile to relieve the operators of one anxiety by disconnecting the furnace from the gas system. After the stoppage, the furnace was put on-wind and blowing-out began.

### Day 1

Blowing-out is one operation that is never hurried. Details of the blowing-out will be found in the Appendix. Wind was put on the furnace at 6.10 p.m. on 26th September after the preparatory stoppage. At 9 a.m. on 27th September, coke breeze was showing at all the tuyeres and preparations were made for the last cast, which was completed at 11 a.m. Blast was finally off the furnace at 11.10 a.m. By 12.30 p.m., the hearth jacket had been cut in preparation for the first bear tap. At 1.25 p.m., iron was running into a ladle, and 53 tons of iron were taken off in this way. At 3.25 p.m., burning was started for the second bear tap because slag was showing at the first. Iron was running again at 4 p.m. ; 152 tons of iron were tapped off into prepared sand-beds on the railroads at yard level (*see* Fig. 3).

During these operations below the cast-house floor, all the tuyeres were being clayed up and the goose-necks and blow pipes were being dropped. Because of the possibility of water-gas generation at tuyere level, the clay stopping of the tuyeres was backed up by a brick stopping, and a steel protection plate was cottered in place at each tuyere opening. The stoves were fully isolated and the fan motors were set to blow cold air into the stoves to accelerate cooling. It was checked that steam was under and between the bells before 2-in. bell-spacers were dropped into place and water sprays were fitted around the bell and through the test-rod holes. At the same time, the tap-hole gun and capstan were removed from their position to the maintenance shops for complete overhaul. Foundation bolts were bricked over to prevent damage during subsequent operations.

### Day 2

At 2 p.m. on Day 1, water was turned into the top of the furnace at the rate of 10 gal./min. By 8 p.m., the flow was 70 gal./min. and a water-gas flame was showing at most of the tuyere protection plates. Between midnight and 4 a.m., this water-gas flame was fairly fierce. By 8.30 a.m. on 28th September (Day 2), water flow had been increased to 140 gal./min. All water regulation was carried out by a master valve at the operating-floor level. By noon, water flow was at its maximum, about 280 gal./min., and water was running freely from all round the furnace at tuyere level, so that it was quite safe to proceed with the wrecking of pipework, etc.

By midnight on 28th September, all the bear iron tapped on to the floor had been loaded and taken away. Electricians had stripped most of the main-hoist gear for overhaul, and the motors were in the shops. Civil engineers carried out minor alterations to the railroads to enable cranes, wagons, etc., to operate later on without interference to the normal production traffic of the other furnace.

### Day 3

At 7.30 a.m. on 29th September (Day 3), 426,000 gal. of water had gone through the furnace, and it was deemed safe to turn off the water. Up to this time, nobody had been allowed to go above floor level. All instruments had been removed to the shop for overhaul.

At 9 a.m., the mechanical engineers began to strip the furnace top. The pebble chute from the bosh to the hole in the cast-house floor was completed during

**Fig. 5—Loader at work on temporary steel ramp in front of the tapping hole**

the afternoon and breaking-in through the bosh began at 6 p.m. By 9 p.m., 405 tons of pebbles had been discharged to ground and were being loaded by a $\frac{3}{8}$-cu. yd. excavator into lorries and dumpers.

At the same time, a window 4 ft. 6 in. high by 6 ft. 0 in. wide was cut through the hearth jacket and the stave coolers behind. Stack coolers were being drawn all this time, and 130 were drawn before midnight. In this connection, material assistance was obtained from a pneumatic impact wrench. The furnace pipework was almost completely burnt off by this time. All pipework is burnt off and such things as brass unions, etc., are salvaged and reconditioned after the furnace has gone into production.

**Day 4**

On Day 4, a further 470 tons of material were discharged from the furnace and taken away. The Constructional Department had by now cut four access windows, each about 3 ft. square, into the stack. The remaining 122 stack coolers were drawn.

Bricklayers on this day completed the necessary minor repairs to gas arches, etc., in the bottom of all three stoves. The stoves were still too hot for work to proceed in the top.

As soon as the first cigar coolers had been drawn and the access windows had been cut, a gang of men followed behind, drilling holes in readiness for shot-firing.

At 10 p.m., I.C.I.'s blasting experts began operations and, working through the night, fired 57 shots through stack-cooler holes to demolish the furnace brickwork.

At the end of this day, all the top gear above the bell and hopper had been dismantled and lowered to ground level. All the furnace pipework had been dismantled. The horseshoe main had been inspected and found to be in good condition.

**Day 5**

Raking out, drilling, and blasting continued on Day 5. Two stoves were inspected in the top and found to be in such good condition that no repairs were necessary, and so they were sealed up.

A steel ramp 24 ft. long and 12 ft. wide was installed in front of the taphole so that a Muir-Hill loader could get up to the furnace to handle wreckage, as demolition of the furnace below the bosh 'pebble' chute proceeded (*see* Fig. 5).

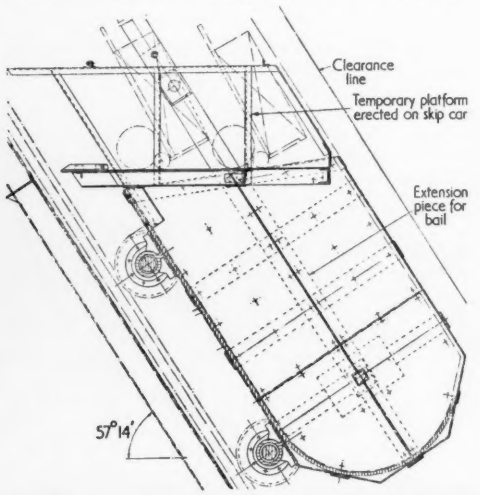



**Fig. 6—Alterations to skip car for carrying brick trucks**

A gale was blowing throughout the day, but the rigging gang worked until midnight to lift the bell and hopper out of the furnace and deck it on the furnace top. A brief description of how the bell and hopper were tied together for lifting is given in the Appendix. On Day 5, 290 tons of demolition material were taken away, and the altered bails fitted to the main-hoist skips for brick handling were in place (*see* Fig. 6).

**Day 6**

The stove chimney flues were inspected, found to be in very good condition, and swept before being closed.

By noon, the bell and the two halves of the main hopper had been landed on ground level. This was more than 48 hr. in advance of the previous best time for this job, so that hopes were already being entertained that the 35-day schedule would be beaten by at least a week. Everybody concerned was therefore informed that the blowing-in date of the furnace had been brought forward by seven days. Nobody seemed to be either surprised or perturbed by this new instruction.

The performance of the riggers and engineers on this day was almost beyond praise. A gale was blowing and 0·47 in. of rain fell between 6 a.m. and noon. Conditions were far from ideal for difficult rigging of this nature.

By 8 p.m., the swinging stage was in the furnace top, and the joiners had completed the decking of it by 11 p.m. The constructional staff immediately began blanking-off the four uptakes from the stage; this job was completed by 4.30 a.m. The wrecking gang then took over and began wrecking the furnace lining from inside.

Because by this time about 150 shots had been fired through the stack-cooler holes, the lining was easily wrecked and good progress was made. During this day, the brickwork exposed in the hearth window had been drilled and the holes cooled, and eight shots were fired.

Painting had started the day the furnace blew out, and arrangements were now made to augment the painting gang, in view of the altered blowing-in date.

On this day, 230 tons of material were taken from the furnace.

**Day 7**

On Day 7, trouble was encountered with pieces of concrete and throat armour and big pieces of scab, which were blocking the chute from the bosh. However, a large ingress hole had been made in the tuyere section immediately above the taphole, and most of the rubbish was extracted here. It was being handled by a mechanical loader into a dumper on the cast-house floor, which tipped into wagons through the service road hatch. By this time, all the bosh and tuyere breast steelwork had been completely wrecked and breaking-in was proceeding all round the furnace.

The electricians had completed overhauling the hoist motors and were engaged in re-assembly of the hoist gear.

**Day 8**

On Day 8, the furnace was completely wrecked to a depth of 54 ft. from the top deck. Uptakes, risers, downcomers, etc., had been inspected by now, and bricklayers were carrying out the necessary minor repairs. All the hoist gear was re-assembled on this day.

**Day 9**

Day 9 was a very busy day. The hoist had now been finished and was ready for handling bricks. Limits, etc., were set during this day. Wrecking was down to the lintel. The brickwork for 6 or 8 ft. above the lintel was only about 18 in. thick, but it was almost completely vitrified, and 46 shots were fired to remove it.

Conditions in the stack were exceptionally bad because of heat, steam, and dust, but wrecking proceeded at such a rate that it was necessary to bring a second Chaseside shovel and a second dumper on to the cast-house floor. At midnight, the wrecking gang had finished with the swinging stage and handed it over to the Constructional Department, who hoisted it to the top of the furnace and used it to erect a platform (shown in Fig. 7), from which repairs to the top cone would be effected.

Shortly before midnight, communication was established *via* the window in the hearth jacket with the loose material inside the hearth, and red-hot coke ran fairly freely for some hours. Very good progress indeed was made on this day by everybody ; Day 9 was in fact the turning point of the job.

**Day 10**

By noon on Day 10, the whole of the brick-handling structure for the furnace top had been hoisted up. The 10-ton electric blocks for handling the extending scaffold were assembled on the structure on the ground. During the descent (wrecking), the scaffold was suspended from the bell-changing trolley, and winch power was obtained from a steam crane on ground level. By midnight, the top structure was ready for handling bricks. During this time, the boilersmiths were erecting a sealing platform across the lintel ; starting at noon, they completed the platform at 3.30 a.m.

Raking-out was proceeding, and at the end of the day everything above the top of the hearth jacket had been completely demolished, and the material in the hearth had been removed to 3 ft. below the top of the hearth jacket. Bricks had been loaded from the stock piles during the previous two or three days, and the brick-loading wharf was now set up ready for use. Stack coolers had been unloaded in the cast house and were being hoisted to the various platforms ready for installation.

During the night, some trouble was encountered in decking the main skip and some time was lost in carrying out minor alterations.

**Day 11**

At 1 p.m. on this day, the first load of bricks was on the lintel platform and the bricklayers began relining. Details of the brick-handling equipment and methods are given in the Appendix.

Removal of the material from inside the hearth had proceeded far enough for the boilersmiths to begin erecting the blasting cover at 6 p.m. This was in place by 10.20 p.m. Distance pieces 5 in. thick were secured between the blasting cover and the top of the hearth jacket ; this was necessary to give clearance for the removal of the old stave coolers without disturbing the blasting cover. The top of the furnace foundation was being cut to take a new design of water trough. At the end of the day, the first 3 ft. of the stack brickwork was in place. Furnace bleeders were inspected and cleaned and minor repairs were carried out. All demolition, etc., above cast-house floor level had now been completed and all rubbish had been taken away. The shovels and dumpers were removed from the cast house. By this time, 2620 tons of old bricks, pebbles, coke, scab, etc., had been demolished and removed ; this tonnage included no metals. The loading of this tonnage under the difficult conditions was made possible only by the use of mechanical shovels and trackless vehicles.

Before bricklayers started work in the stack, all the stove repairs had been completed, and the stoves were already being warmed up again ready for blowing.

**Day 12**

On Day 12, the boilersmiths unloaded the new bosh jacket in the cast house and began erecting it.

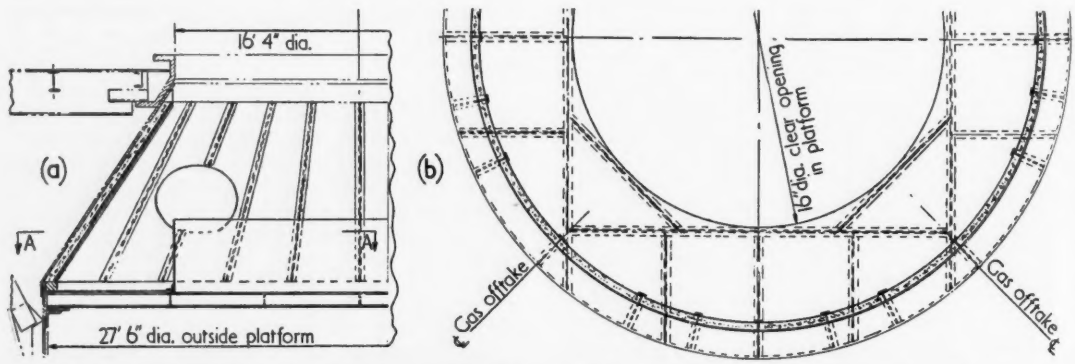



**Fig. 7—Arrangement of lining and temporary platform in furnace top cone : (*a*) Section through cone, (*b*) sectioned plan on *AA***

Wrecking was proceeding simultaneously with building, erection of steelwork, erection of pipework, etc. Figure 8 shows how, at this time, seven different gangs of men were at work at seven different levels. The importance of this cannot be overemphasized. It was only by making this provision that the speed of relining could be materially increased. Figure 8 is, in effect, an epitome of fast relining. Without arrangements to make possible this simultaneous employment of different gangs, relinings can take a very long time. The cost of the necessary temporary platforms has been amply justified. Without the isolating scaffolds at the lintel and the top of the hearth jacket and the temporary platform at the bottom of the top cone, only one gang would be able to work inside the furnace.

**Day 13**

By 5 p.m. on Day 13, the bosh jacket was completely in place, checked, and set ready for welding, which proceeded immediately. At this stage, the tempo of the job necessitated putting the general stores on to shift work.

**Days 14 and 15**

Day 14 saw the completion of welding of the bosh jacket and the commencement of erection of the new tuyere breast steelwork. Erection began at 6 a.m., and the jacket was fully bolted in position by 10 p.m. Wrecking of the hearth was completed, so that the furnace was completely demolished, with the exception of the stave coolers, which had been left as a protection for the hearth jacket against the blasting that took place inside the hearth.

Because of the very successful bear taps on Day 1, very little titanium nitride or iron was found in the bottom of the furnace. Much vitrified brick, however, had to be removed.

Removal of the stave coolers began at 8 p.m. on Day 14 and was completed by 7 a.m. on Day 15. The stave coolers, each 13 ft. 6 in. long and about 4 ft. 0 in. wide and weighing about 5 tons, were removed through the access window in the hearth jacket. Once the blasting cover was in place on Day 11, all demolition material had to pass through this window. The last stave cooler was out of the furnace at 7 a.m. on Day 15, and this marked the completion of demolition.

The stack brickwork had been built to a height of 38 ft. above the lintel, and the stack coolers had been completely piped to a height of six rows. The temporary ramps, chutes, etc., on cast-house floor level were demolished and removed during Day 14.

The last two shots were fired in the hearth. During the demolition, a total of 298 shots was fired. This figure may sound rather large, but the total weight of explosive used shows that most of the shots were only of a few ounces. The following is a summary of the explosives used on the work :

| | | | |
|---|---|---|---|
| Polar Ammon Gelignite | $1\frac{1}{4}$ in. × 4 in. | cartridges | 173 lb. |
| ,, ,, ,, | $\frac{7}{8}$ in. × 4 in. | ,, | 1 lb. |
| Submarine Blasting Gelatine | $1\frac{1}{4}$ in. × 4 in. | ,, | 22 lb. |
| Sheathed Ardex | $1\frac{1}{4}$ in. × 4 in. | ,, | 12 lb. |
| No. 6 electric detonators | | | 210 |
| No. 8 ,, ,, | (special) | | 88 |

As soon as the last stave was out of the furnace, the bricklayers started work in the bottom. This necessitated borrowing bricklayers from the steelworks, to avoid depleting the crew at work in the stack. The Appendix gives a statement showing the disposition of the bricklaying force at this time.

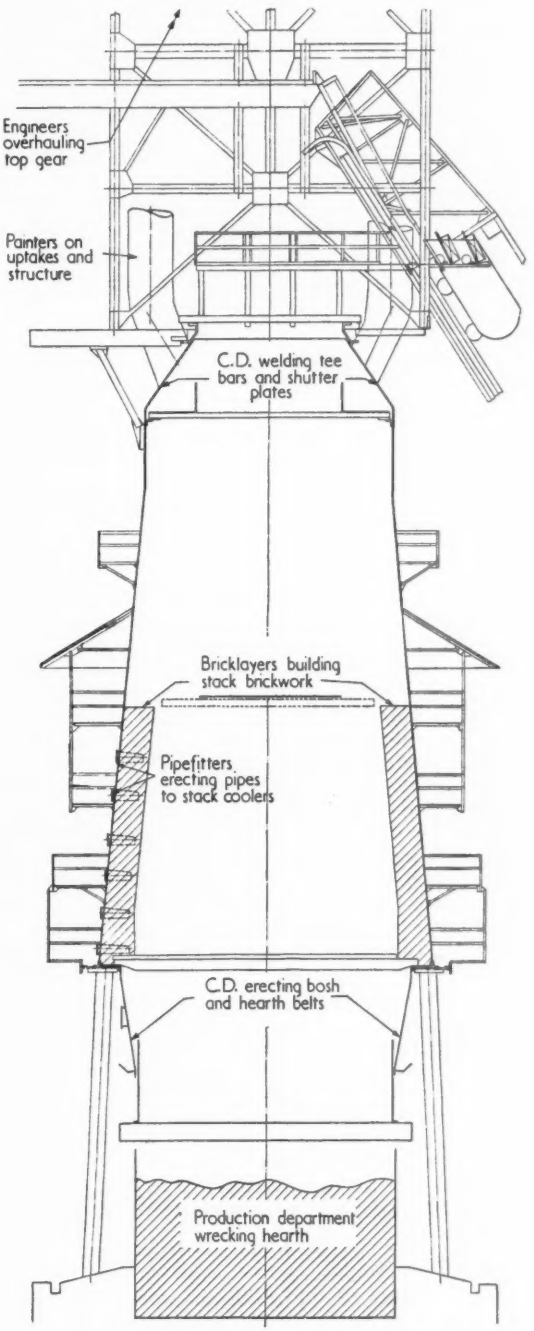

Engineers overhauling top gear
Painters on uptakes and structure
C.D. welding tee bars and shutter plates
Bricklayers building stack brickwork
Pipefitters erecting pipes to stack coolers
C.D. erecting bosh and hearth belts
Production department wrecking hearth

**Fig. 8—Diagrammatic arrangement showing simultaneous employment of labour force**

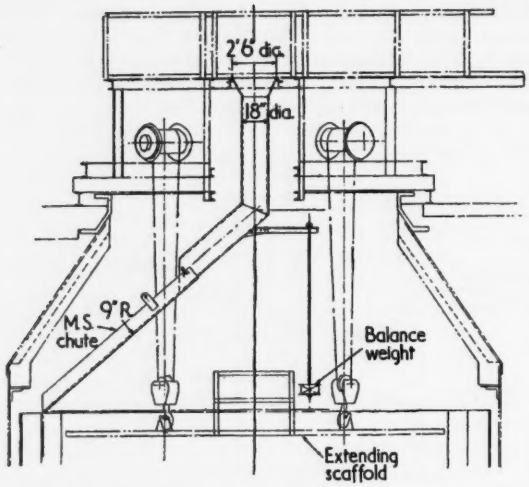



**Fig. 9—Chute for pouring refractory concrete behind throat armour**

At the end of Day 15, brickwork was completed in the stack to within 20 ft. of the top of the throat armour. All the stack coolers had been piped and the first six rows had by now been stemmed, pointed, and shrouded.

**Day 16**

As soon as the hearth bottom was levelled off ready for the installation of the corrugated hearth blocks, the boilersmiths began replacing the hearth-jacket window ; a patch had been prepared previously, and the edges of the hole had been similarly prepared for welding. This job began at 8 a.m. on Day 16, and internal welding was completed by 6.15 p.m. Final external welding was completed next day.

As bricklayers reached each successive access window in the stack, the boilersmiths replaced these with prepared patches. The main object of the access window was to give the easiest possible entrance and exit during stack relining. Having to negotiate long rope-ladders to get to their place of work is not conducive to fast working by any group of men.

During the night of Day 16, bricklaying was suspended inside the hearth. The previously assembled tuyere breast steelwork was, at this time, resting on the blasting cover. The tuyere breast steelwork was now lifted up to permit removal of the blasting cover and was lowered into position for final setting.

At the same time, alterations to No. 2 slag-notch runner and the installation of No. 3 slag notch were in progress. The new steel water-course on top of the foundation block was being installed.

Overhaul of the coke screens and motors was completed on this day and the screens were put back into position.

**Day 17**

Early on Day 17, all bricklayers were taken out of the stack for 4 hr. to permit the boilersmiths to dismantle the platform at the bottom of the top cone, used for erecting the steel lining to the cone. During this period, the bricklayers were at work in the hearth. By 5.15 a.m. on 14th October, the stack lining had been completed, with the exception of the top row of throat armour and the pouring of the concrete behind the throat armour. All bricklaying was now concentrated in the hearth.

Civil engineers moved on to the furnace top to prepare for pouring the concrete behind the throat armour. Temporary flood-lights had been fixed on the furnace top and dustcatcher top, so that concreting, rigging, and top steel erection could continue during hours of darkness. Concrete was mixed on ground level and taken to the furnace top in contractors' barrows by means of the main skips, altered primarily for brick handling.

**Day 18**

At 9 a.m. on 14th October, the civil engineers began pouring the concrete behind the throat armour ; 31 cu. yd. of concrete were poured and finished by 6 p.m. Figure 9 shows the arrangement of the gear used. This gear was altered to permit concrete to be poured between the cone and the steel lining previously erected. This work began at 8.30 p.m. and was finished at 1 a.m.

The top row of throat armour was now laid in place and the insulation behind the former ring was tamped in position. At 7 p.m. on 14th October, all work inside the stack of the furnace was completed.

It should be noted that the closures at the bottom of the uptakes were suspended on steel wires from the uptake inspection covers and were further supported by cleats welded across the bottom of the uptakes. At the last moment of work in the stack, the angles welded across the bottom of the uptake to support these closures were burnt off, so that only wire ropes held them in place. This was done to avoid the necessity of going into the furnace after it was filled. On previous occasions, this job occupied three or four valuable hours during the hectic closing stages of the job. All that was now necessary was to disconnect the wire rope and drop the closure into the furnace.

By this time, the hearth brickwork was up to just below taphole level. All bricklayers were concentrated in the hearth, and at the end of Day 18 the hearth brickwork was completed to the centre-line of the slag notches.

During the day, a temporary pipe was inserted through a third-row stack cooler and hot blast was turned into the stack at 2.15 a.m. Work was immediately started to dismantle the temporary top gear and to prepare the main hoist and skips for their normal duty.

All gooseneck saddles were in place, but were now blanked-off while hot blast was going into the stack. At 3 a.m., riggers and boilersmiths began removing the brick-handling structure on top of the furnace. All this was on ground level by 7.30 a.m., so that installation of the top gear could proceed.

**Day 19**

Day 19 turned out to be very foggy, but in spite of that the first half of the hopper was on the furnace top at 8.30 a.m. The second half of the hopper and the large bell were decked on top of the furnace by

11.55 a.m. The hopper was bolted up and the bell and hopper were strapped and lowered into position by 4.30 p.m.

The bell rod, which is 46 ft. long, was on the furnace top by 7 p.m. and was fastened to the big bell by 6 a.m. on 16th October.

At the end of Day 19, the bricklayers had covered in the first two rows of plate coolers. Cleaning of the dustcatcher and of the dirty-gas main was completed and these items were closed up.

The new turn-out from the slag road to serve No. 3 notch was completed by the platelayers.

**Day 20**

Day 20 saw the completion of the new gunited lining to the coke bunkers, together with the fitting of new chutes and gates.

The main hoist was now ready for its normal duty. The top seal, distributor, and receiving hopper were set in place by 7.30 p.m. The lintel platform was cleared of all rubbish and the cathead was fitted for the bricklayers' winch. Figure 10 shows the general assembly of relining equipment.

Stacks of carbon bricks were built up outside all the bosh tuyere openings, in case the brick hoist could not keep the bricklayers fully served. Suspension of the bricklayers' platform was now transferred from the lintel platform to wire ropes hung through the test-rod holes. Progress by this date was such that it was finally decided to blow in the furnace on Monday, 20th October, at 10.30 a.m. This information was given to everybody concerned. Again, bringing forward the blowing-in date appeared to disconcert nobody.

**Day 21**

During Day 21, the brick-loading wharf at the bottom of the hoist had been completely dismantled and taken away. During mealtimes and other breaks, the boilersmiths began to dismantle the lintel platform. Erection of the furnace-top gear was completed during the day. The taphole gun and its capstan were erected and in position.

**Day 22**

Brickwork was now well up into the bosh, and by the end of Day 21 all the bosh coolers were in place and the blow pipes and goosenecks had been erected. At 6 a.m. on Day 22, removal of the lintel platform began and was completed by 11.30 p.m.

At 1 a.m., bricklayers completed the marrying of bosh brickwork to stack brickwork, so that the lining of the furnace was complete. All the bricklayers were then diverted to such work as slag falls and taphole runners. As soon as the bricklayers left the furnace, all the gear inside was removed and the furnace bottom was cleaned out.

**Day 23**

At 2.40 a.m. on 19th October, all work inside the furnace was completed and hot blast was turned in through the hearth tuyeres. As all work on the furnace top was complete, the 45-ton trolley was removed from the furnace top to be placed in store.

**Day 24**

It is in the last few hours of a hurried relining that the casual observer believes that it will be impossible to have the furnace ready for the scheduled hour. The cast house is a scene of apparently utter confusion—runners, troughs, etc., are being relined, rubbish is being cleared away, last-minute painting is in progress, coke is being shovelled into the furnace through the tuyeres, pipefitters are completing their adjustments and stopping all leakages, and the thousand and one jobs necessary for completion are in progress.

At 7 p.m. on Day 23, the furnace was completely piped up and full water was on. At 6 a.m. on Day 24, all minor leaks, etc., had been corrected. At the same time, all external brickwork, such as cast-house paving and runners, had been completed, and all surplus bricks had been removed from the cast house. The hearth coke had been shovelled into the furnace hearth, all the tuyeres were in place, and the furnace was filled to within 6 ft. of its full stockline by 4.30 a.m.

The last few hours before blowing-in were occupied in washing out the cast house and generally tidying up. Everything round the furnace, such as water, distributor, and steam, was double-checked. All signals were checked and the blower was discharging to the snort valve by 8 a.m. The furnace was lit through the tuyeres at 10.29 a.m. and blast was put on to the furnace at 10.40 a.m. on 20th October, 1952, exactly 22 days 23 hr. 30 min. after blast was taken off at the end of the previous campaign.

## Acknowledgments

To give due acknowledgment to everybody who assisted in the successful completion of the operation described above would be to give a very lengthy catalogue of names. The authors' thanks are due to everybody who assisted with advice, service, or work ; it is impossible to single out individuals. The fact that no names are mentioned in this acknowledgment should emphasize that the authors regard themselves as representing a large number of men who combined to do a job. It is believed, however, that everybody concerned would like an exception to be made in the case of Mr. M. Ferguson of Imperial Chemical Industries, Ltd. (Technical Service Department). Over many years, his contribution to rapid relining has been of great value, and the way in which he has carried out his duties under dirty and difficult conditions has gained the admiration of everybody.

The authors are grateful to the United Steel Companies, Ltd., for permission to publish this paper.

# APPENDIX

## Operational Details

### INSTRUCTIONS FOR BLOWING OUT NO. 9 FURNACE

It must be checked before Saturday that the following items are ready :

(*a*) Water main to furnace top with water meter
(*b*) Three water sprays for test-rod holes and big bell
(*c*) Steam spray for the spare test-rod hole to put steam under big bell
(*d*) Pyrometers for two uptakes
(*e*) Bunkers 3–10 to be emptied ready for pebbles.
(*f*) Tools, safety belts, etc., to be available

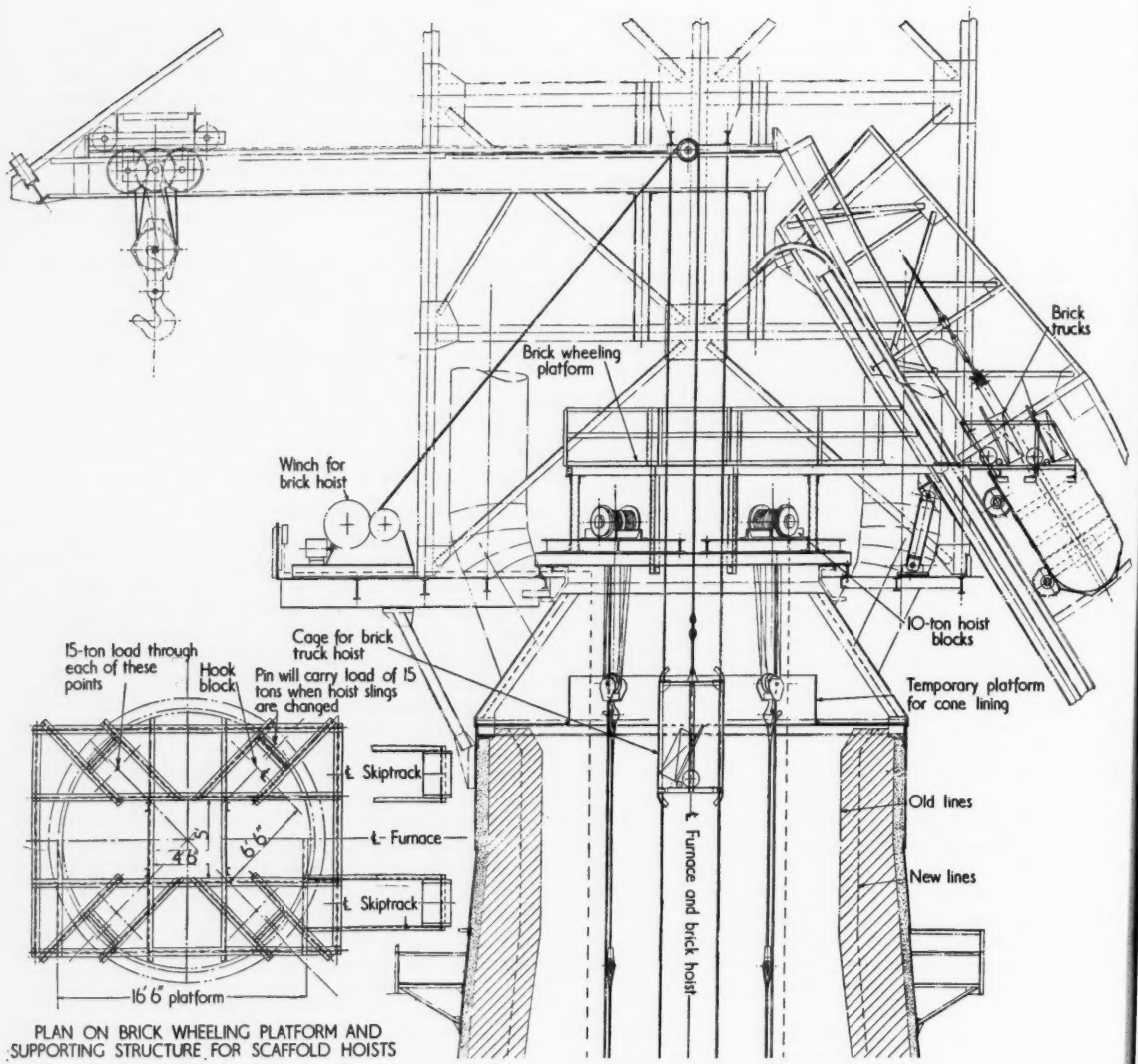

Brick trucks
Brick wheeling platform
Winch for brick hoist
10-ton hoist blocks
Cage for brick truck hoist
15-ton load through each of these points
Hook block
Pin will carry load of 15 tons when hoist slings are changed
Temporary platform for cone lining
℄ Skiptrack
℄ Furnace
℄ Skiptrack
Old lines
New lines
℄ Furnace and brick hoist
16′ 6″ platform
PLAN ON BRICK WHEELING PLATFORM AND SUPPORTING STRUCTURE FOR SCAFFOLD HOISTS

**Fig. 10*a*—Section through top of furnace, showing relining equipment (*see also* Fig. 10*b*)**

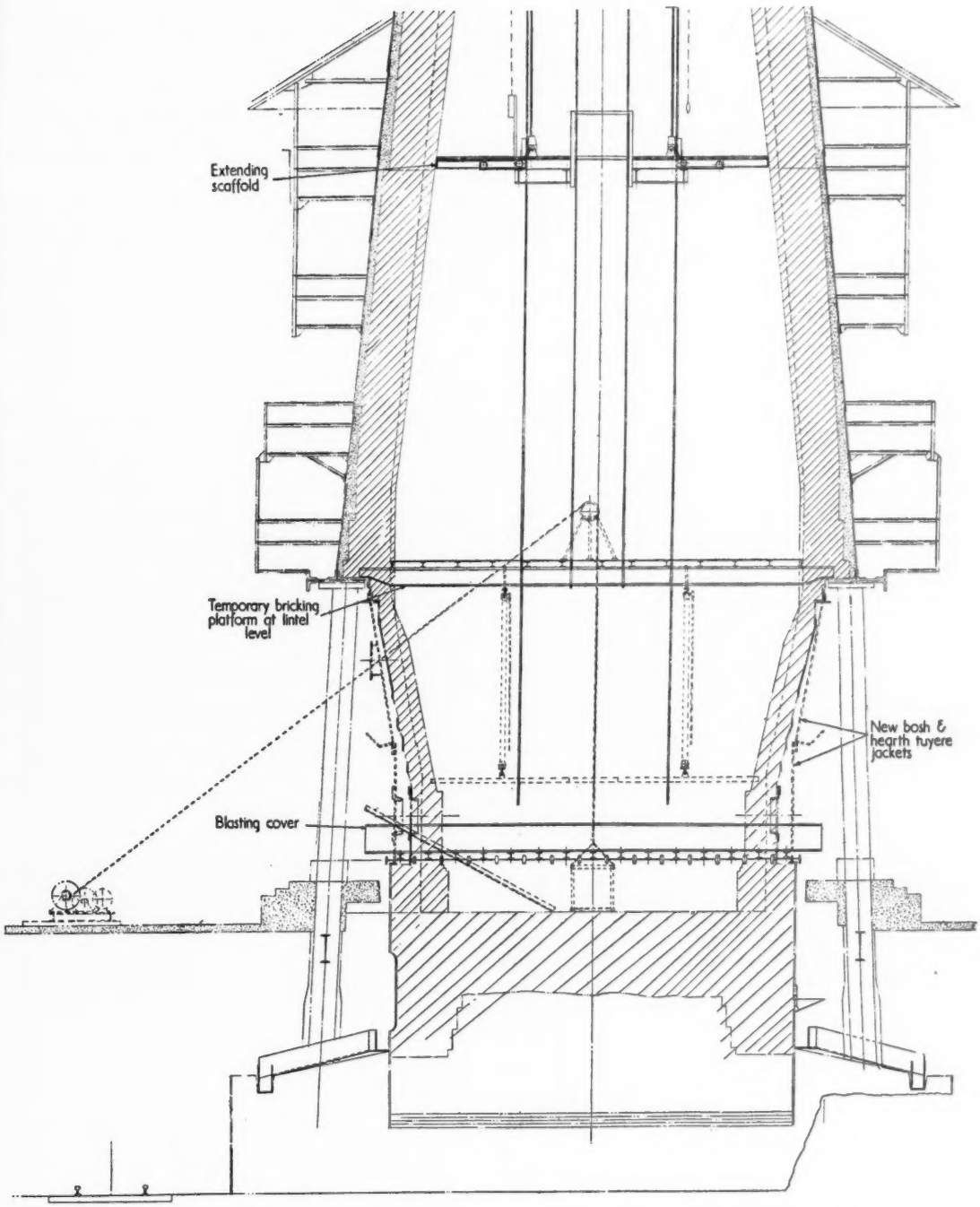



**Fig. 10*b*—Section through hearth and stack, showing relining equipment (*see also* Fig. 10*a*)**

(*g*) 200 tons of coke nuts to be tipped in bunkers 25–30
(*h*) Passenger lift and cast-house crane to be overhauled.

**Blowing-out Schedule**

Twenty-four hours before the start of blowing-out, put the furnace on a straight-ore burden. By 5 p.m. on Friday, 26th September, both dustcatchers should be completely emptied. Coke bunkers should be emptied at this time. After the 5 p.m. cast on Friday, 26th September, the following work is to be carried out :

(1) All bosh tuyeres to be clayed up
(2) Tuyeres 1 and 14 to be changed to 15 in. × 6½ in.
(3) The 72-in. goggle valve to be swung to isolate the furnace from the gas system
(4) All water sprays to be tested at the levels to be used
(5) Insert thermocouples into north-west and south-east uptakes and connect to the in-wall temperature recorder
(6) All inflammable material must be removed from the furnace top.

After blast is on, on Friday evening, with distributor set at five-skip dumping and a weight of 3300 lb. per skip, charge 135 skips of coke nuts. Then set the distributor to four-skip dumping and charge pebbles at a weight of 48,000 lb. per charge. Maintain a normal stockline until commencement of the last cast and then run the stockline down to 10 ft. to allow room for inserting test-rod sprays. It is calculated that about 750 tons of pebbles will have to be charged to fill the furnace from the top of the bosh.

Cast at 6 a.m. on Saturday and work for the final cast at 11 a.m. If the pebbles have been charged, or if coke nuts or pebbles are seen at the tuyeres before this, cast the furnace. The last cast should be as low in the tapping hole as possible at a steep angle. Cast the furnace with 10–12 lb. of blast. At the end of cast, take the furnace off blast. A charge of pebbles should be left on the big bell for men to stand on when fitting bell spacers.

Water and steam sprays will now be fitted and the bell spacers fastened to the big bell. The top spray-cocks are to be turned wide open ; water to be controlled by the valve at ground level. When doing so, consult the record of water-meter readings from blowing-out No. 10 furnace. The furnace will be kept draughting back and the engine blowing up to the snort valve until all blow pipes are dropped, tuyeres clayed up, brick stoppings in, and tuyere protection plates fitted.

When work on top is finished, close and fasten all seal doors and carry out a final inspection of the top. Make sure that all personnel are away. Rope off all access stairways and deposit the passenger-lift fuses at the foreman's office. Then lower the big bell twice to position the spacers. Turn on water at about 10 gal./min. It is anticipated that it will be necessary to put water in the furnace for 36 hr. Nobody will be allowed on the furnace top or off ground level until water has been turned off.

## REMOVING BELL AND HOPPER

After the reception hopper, distributor gear, and top seal had been removed, in that order, two 12 in. × 8 in. joists were thrown across the top of the hopper, one on each side of the bell-rod. Links were fastened to the joists to hold the big bell by means of the lifting lugs on the bell. When the bell was secured, the bell rod was dismantled and removed to ground. A stub rod about 3 ft. long was then fitted to the bell. The top trolley, which had already been reeved, picked up the bell and hopper together by means of this stub rod. As soon as the bell and hopper were clear of the furnace top, six 12 in. × 8 in. joists were placed across the top of the crown casting. The bell and hopper were then lowered on to this temporary platform.

The four-piece hopper was then split into two sections. The front section was lowered to ground, followed by the bell and then by the second half of the hopper. It was impossible to have a vertical descent from the end of the furnace-trolley beam. A 10-ton travelling crane used as a winch took the free end of the block rope, and another crane was used to pull the load clear of the cast-house structure. Reference to Fig. 10 will show the need for this racking-out of big loads.

## BRICK HANDLING AND BRICKLAYING

Experience has shown that bricks can be laid as fast as they can be supplied to the bricklayers. The number of bricklayers available was limited and outside help was not sought in this connection. Most of the bricklayers had had experience of several relinings, so that the laying rate was fairly high.

In the upper stack, where the work is straightforward, the average number of bricks laid per 8-hr. shift per bricklayer was 800. Of these 800 bricks, about 500 were 13½ in. × 6 in. × 3 in., with equivalent compass, and the remainder were 9 in. × 6 in. × 3 in., with equivalent compass. With eight bricklayers per shift, the supply of this large number of bricks to the stage inside the furnace called for special arrangements. Wagons and bricks from the stockpiles were brought in predetermined order to the steel unloading wharf that had been set up parallel to the scale-car

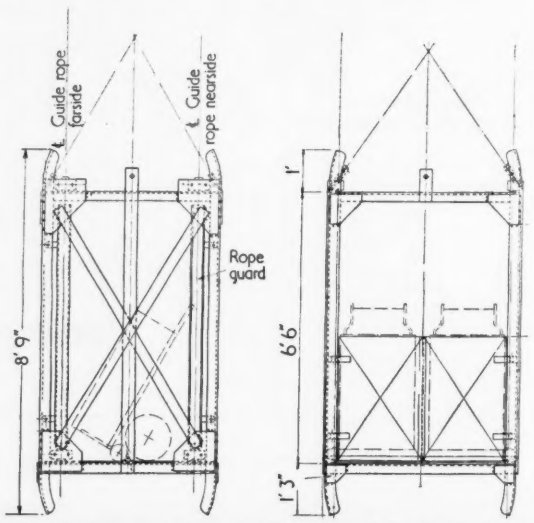



**Fig. 11—Views at right-angles of cage for relining hoist**

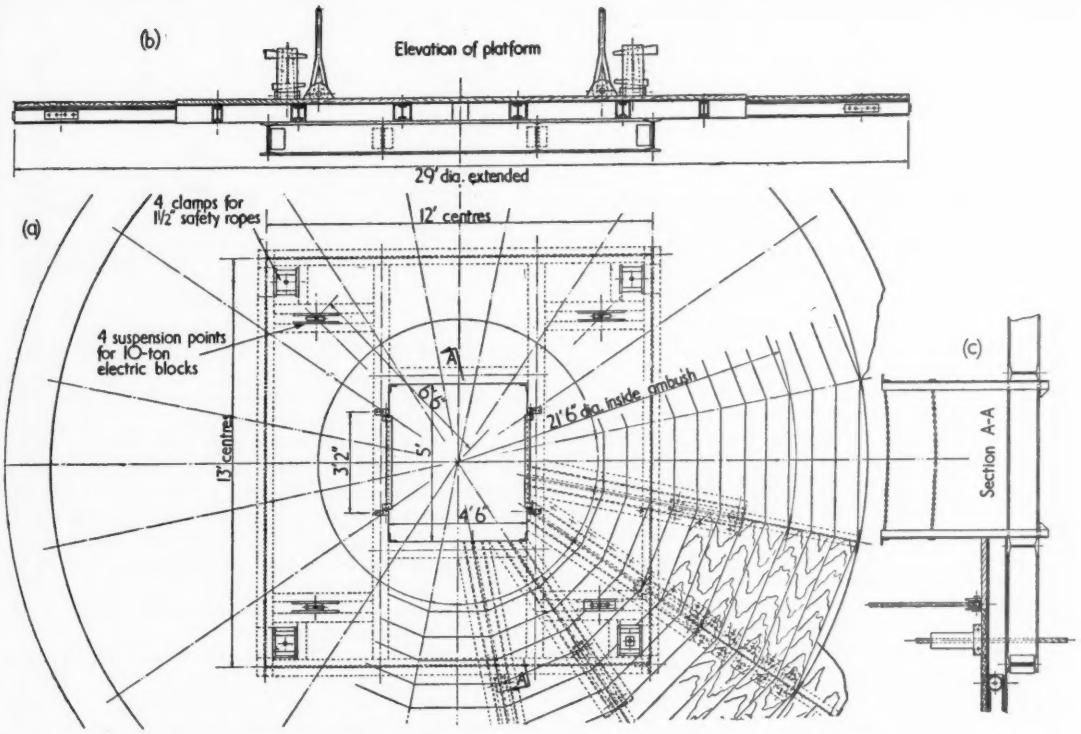



**Fig. 12—Plan, elevation of platform, and section of extending scaffold**

track. This wharf was about 12 ft. wide and about 90 ft. long. Telephonic communication was established between this wharf and the foreman bricklayer inside the furnace.

Bricks were unloaded from the wagons into Warry barrows. These self-locking easy-dumping barrows will take 28 13½-in. bricks. The main furnace skip, which had previously been modified with a covering platform and extended bail, will accommodate two of these barrows (*see* Fig. 4 for the general arrangement at the bottom of the hoist and Fig. 6 for alterations to the skip car).

On arrival at the top of the furnace, the barrows were wheeled along the temporary platform, shown in Fig. 10, and thence to the cage of the relining hoist. The hoist cage is shown in Fig. 11. This cage took two Warry barrows down to the extending swinging platform on which the bricklayers were working. From the cage, the barrows were wheeled and dumped to a point on the platform where the bricklayer could pick up bricks without walking from the point at which he was laying them. The winch for handling the brick hoist was stationed on the top deck of the furnace (*see* Fig. 10).

The extending stage was designed by Appleby-Frodingham engineers after the design of Trexler* (*see* Fig. 12). The stage was suspended from the top of the furnace by wire ropes attached to four Matterson 10-ton blocks. Control of the blocks was by four push-buttons on the swinging stage. As the wind drums would accommodate only 18 ft. of rope, previously prepared ropes of suitable lengths were used, to be joined or shortened as required. As a safety precaution, the stage was clamped to four hanging wire-ropes. which were anchored to the top structure. Figure 13 shows the ingenious clamping device that has been developed for this duty. When the stage was in use and stationary, the load was shared between the Matterson blocks and the safety ropes. When it became necessary to raise or lower the stage, the cotters in the clamps were knocked back so that the load of the stage was transferred wholly to the Matterson blocks.

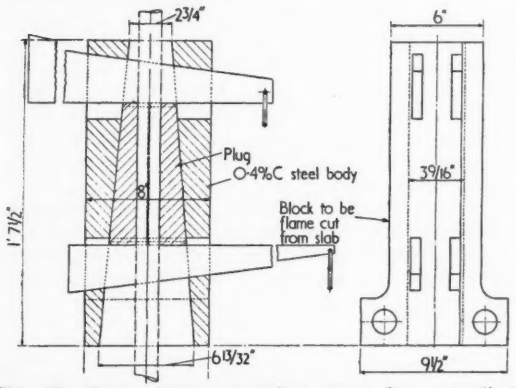



**Fig. 13—Rope clamp on safety ropes for extending scaffold**

* E. W. Trexler, *Amer. Inst. Min. Met. Eng., Blast Furn. Raw Mat. Comm.*, 1943, vol. 3, pp. 98–116.

As soon as the stage was stationary in its new position, these cotters were tightened, so that the load was again spread to the safety ropes. The swinging stage was designed to operate from a minimum diameter of 18 ft. to a maximum diameter of 29 ft. All the wooden decking planks were match-marked for rapid fitting. This stage was used for all the bricklaying from the lintel upwards.

When bricklaying was transferred to the hearth of the furnace, a temporary wooden platform was erected on supports when the working height became too high for the men to stand on the hearth floor. This platform was used until the top of the hearth was reached.

For bricking the bosh, a light wooden scaffold, manipulated by chain blocks suspended from four wire ropes anchored to the top of the furnace, was used. A hatchway was cut in the centre of this light platform, through which a small skip could pass. The skip was lifted by a rope passing over a cathead on the lintel platform to a winch situated on the cast-house floor. Bricks were fed to this skip by means of roller conveyors or a polished steel channel leading from tapping hole and slag notches (*see* Fig. 10).

Dry jointing clay was taken to the top of the furnace by either passenger lift or the main skip, as opportunity offered. The clay was mixed in a large tub on the furnace top. The mixed jointing clay was then lowered to the bricklayers' stage in buckets as required.

The total strength of this gang for each 8-hr. shift when relining the stack was 19—six bricklayers, two apprentices, and two labourers were engaged on the extending stage ; one labourer was mixing clay on top of the furnace ; two labourers were unloading the barrows from the main skip and loading them on to the brick hoist ; one was driving the winch on top of the furnace ; and five were unloading bricks from rail wagons to Warry barrows and putting these on the main hoist.

In addition to the above, four bricklayers from the steelworks and four labourers were used on such jobs as downcomer repairs, and were at one period engaged on hearth brickwork, when stack brickwork was proceeding simultaneously.

## LABOUR FORCE

The following is a brief summary of the labour employed on the site, giving the maximum number in each section. All the gangs did not deploy maximum strength at the same time.

The labourers are shown in one group because they were virtually pooled for the duration of the job. A labourer could be, and often was, wrecking inside the furnace one day and helping the bricklayers next day.

In addition to the number listed in the following summary, there were many shop men engaged on the overhaul of motors, instruments, etc., and a small number of platelayers on the necessary railroad work.

| | Days | Each of 3 Shifts | Total |
|---|---|---|---|
| Bricklayers | 2 | 6 | 20 |
| Fitters | 5 | 4 | 17 |
| Electricians | 2 | 1 | 5 |
| Riggers | 15 | 6 | 33 |
| Burners | 2 | 2 | 8 |
| Crane drivers | 11 | | 11 |
| Boilersmiths, welders, erectors, etc. | 40 | | 40 |
| Labourers | 61 | 56 | 229 |
| Pipefitters | 3 | 3 | 12 |
| | | Total | 375 |

## RIGGING TACKLE, etc.

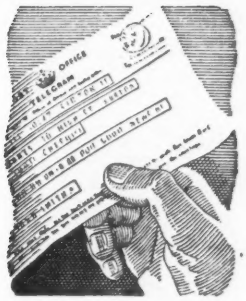
Four sets of 5-ton chain blocks were used. Two sets were hung in 28 ft. × 1 in. dia. wire-rope slings on each side of the big-bell rod, with an 8 ft. × 1 in. dia. sling on the rod for lifting the rod out of the big bell complete with the small-bell rod and wearing cones. Two sets were hung in 34 ft. × 1 in. dia. slings for transferring the big-bell rod, etc., on to the furnace platform before lowering it to ground level. One set of $\frac{5}{8}$-in. wire-rope blocks, reeved 2 and 1, with 600 ft. of rope, were hung from the 40-ton trolley for lowering all material to ground level, with the exception of the big-bell rod, the big bell, and similar heavy lifts. These blocks were also used for lifting most of the material required on top.

The 40-ton trolley blocks were reeved with 1250 ft. × 1 in. dia. 6/37 wire rope, reeved 4 and 3. The fall of the wire passed through a single block with a safe working load of 10 tons anchored to the bottom of the dustcatcher supports, and then to the drum of a 10-ton steam crane, which was used as a winch. One set of $\frac{5}{8}$-in. wire-rope blocks, reeved 3 and 2, with 1000 ft. of wire, were used for pulling out lifts when lowering or hoisting, so as to clear the cast-house structure. These blocks were also anchored to the dustcatcher legs, with the fall of the wire passing through a snatch block to another 10-ton steam crane. A set of 8 ft. × $1\frac{1}{8}$ in. endless slings were anchored on to the lifting brackets inside the main hopper. For safety reasons, a $\frac{7}{8}$-in. dia. wire rope was passed over the block sling and through the bottom hole at each corner of the hopper section, so that the hopper was lifted level for easy decking on top.

The swinging stage was suspended by 14 ft. × $1\frac{1}{2}$ in. dia. wire-rope slings. Four of these were fitted with galvanized thimbles spliced at one end for hanging on to the Matterson winch hooks. The others were fitted with solid-steel eyes to take a 2-in. dia. pin. The remaining eight slings were fitted with solid-steel eyes in one end and an open conical socket in the other end. The safety ropes for the scaffold were also $1\frac{1}{2}$ in. dia., and $\frac{3}{4}$-in. locked-coil ropes were used as guides for the brick cage.

During blowing-out, on the cessation of charging, one of the main skips was fastened by means of wire slings and shackles at ground level ; this was to give slack wire in the hoist house, so that the hoist-house motors could be passed over the hoist drum.

# N E W S



ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

## THE IRON AND STEEL INSTITUTE

### Special Report on Spectrographic Analysis

The latest addition to the series of Special Reports published by the Institute is a report on "*Spectrographic Analysis of Low-Alloy Steels.*" prepared by the Spectrographic Analysis Sub-Committee of the British Iron and Steel Research Association.

The Report surveys the spectrographic techniques employed in this country for the analysis of iron and steel, and a recommended method (based on the most successful of the alternative procedures examined) for the spectrographic analysis of low-alloy steels has been drawn up and given extensive trials on a series of chemically analysed standards, with very satisfactory results. The text has been divided into sections corresponding broadly to the sequence of analytical operations required. The applicability of alternative procedures or accessories has been described in several instances, and theoretical considerations and detailed operating instructions have been included where necessary.

The Report, No. 47 in the Series, is fully illustrated with diagrams and photographs, and is bound in cloth with stiff board covers. It can be obtained from the Offices of the Institute at 15*s.* per copy, post free (7*s.* 6*d.* to Members).

### Special Report on Refractory Materials

A few copies of Special Report No. 26, "*First Report on Refractory Materials*," have now become available and can be supplied at £1 5*s.* 0*d.* (members 15*s.* 0*d.*). Orders will be dealt with as received so long as copies remain available.

## NEWS OF MEMBERS

▶ Monsieur L. ARBEL has become President of Etablissements Arbel, Paris.

▶ Dr. D. BINNIE has been awarded the D.Sc. degree of Glasgow University.

▶ Mr. R. V. BRYAN has taken up an appointment with Henry Wiggin and Co., Birmingham.

▶ Mr. E. S. CORNWALL has been appointed General Manager and Chief Engineer with the Southern Electric Authority of Queensland, Brisbane, Queensland, Australia.

▶ Monsieur L. DAUM has relinquished his post as Director General of the Aciéries de la Marine et d'Homécourt, and is now a member of the Haute Autorité de la Communauté Européene du Charbon et de l'Acier.

▶ Mr. J. D. DICKERSON has left the Republic Steel Corporation, New York, and has taken up the appointment of Chief Metallurgist with the Crucible Steel Co. of America, Midland, Pennsylvania.

▶ Sir JOHN DUNCANSON, an Honorary Vice-President of The Iron and Steel Institute, has retired from the various boards of the companies in the Lithgow Group.

▶ Mr. T. W. EDWARDS has retired from Joint Managing Directorship of the Park Gate Iron and Steel Co., Ltd., after 54 years of active association with the company. He joined the company in 1898, and 18 years later was appointed Secretary, a position he later combined with that of Commercial Manager. He was appointed Assistant Managing Director in 1945, and three years later was appointed to the Joint Managing Directorship.

Mr. Edwards will continue his association with the Company as a special Director and Consultant, and also retains his seat on the Board of British Basic Slag Ltd., of which he is Deputy Chairman.

▶ Mr. J. F. EWING has taken up an appointment in the Research Department of the Tubular Products Division of the Babcock and Wilcox Company, Beaver Falls, Pennsylvania, U.S.A.

▶ Mr. M. M. HALLETT has been appointed Director of Sales to Sheepbridge Engineering Ltd.

▶ Mr. J. HEY has left the Consett Iron Co., Ltd., to take up an appointment with the Llanelly Steel Co. (1907), Ltd.

▶ Mr. T. B. V. HIRST has been appointed Chairman and Managing Director of Tekon Ltd.

▶ Mr. D. S. MURTY has transferred from the Technical Development Establishment (Metallurgy), and has been appointed Assistant Director of Technical Development (Inspection and Quality Control) at the Directorate of Technical Development, Calcutta, India.

▶ Mr. B. PODCZASKI has left the Direccion General de Fabricaciones Militares, and is now Managing Director of the Crisoldinie E.N. Steelworks, Buenos Aires, Argentina.

▶ Mr. T. ROBERTS has taken up the appointment of Blast-Furnace Manager with the Cargo Fleet Iron Company, Ltd.

▶ Mr. K. SACHS has been awarded the Ph.D. degree of London University.

### Obituary

Dr. M. A. GROSSMAN, of the United States Steel Corporation, Pittsburgh, U.S.A.

Mr. L. D. HAWKRIDGE, of Boston, Mass., U.S.A.

Mr. E. M. MÅNSSON, of Acierex Ltd., Stockholm, Sweden, on 13th February, 1952.

Mr. W. J. MENKE, of the Shenango-Penn Mold Company, Sharpsville, Pennsylvania, U.S.A., in April, 1952.

## CONTRIBUTORS TO THE JOURNAL

**E. Jarvis**—Assistant Engineer, Blast-Furnace Section of the South Iron Works, Appleby-Frodingham Steel Company.

Mr. Jarvis was educated at the Hanley Higher Grade School and at Stoke-on-Trent Technical College. He

E. Jarvis

R. W. B. Nurse

served his engineering apprenticeship with the Midland Coal, Coke and Iron Co., Ltd., and joined the Appleby-Frodingham Steel Company in 1920.

**B. E. Hopkins, M.Sc.**—Principal Scientific Officer in the Metallurgy Division of the National Physical Laboratory, Teddington.

Mr. Hopkins took an Honours degree in Metallurgy at University College, Swansea, in 1939. He then joined the Research Laboratory of the Mond Nickel Co., Ltd., Birmingham, where he worked on alloy steels and cast irons. In 1946 he was awarded the M.Sc. degree of the University of Wales. A year later he joined the National Physical Laboratory, and has since been working on the effects of alloying elements on the transition from tough to brittle fracture in high-purity iron. During 1947 Mr. Hopkins was seconded as a liaison officer to the British Commonwealth Scientific Office, Washington, D.C.

**R. W. B. Nurse, M.Sc., F.Inst.P.**—Senior Principal Scientific Officer and Deputy Head of the Chemistry Division, D.S.I.R., Building Research Station, Watford.

Mr. Nurse was born at Bedford in 1913, and was educated at Southall Grammar School and at Acton Technical College, taking the London External degree in Physics in 1934. After a short period in industry he joined the Building Research Station of the Department of Scientific and Industrial Research as a Technical Assistant. During the War he was on loan to Army Operational Research, returning to the Building Research Station in 1945 to take charge of the Silicate Chemistry Section. Mr. Nurse is at present responsible for work on the chemistry of cement and concrete, clays and clay products, general mineralogy, silicate chemistry, and the use of metals in buildings.

**H. G. Midgley, M.Sc., Ph.D., F.G.S.**—Senior Scientific Officer and Head of the Mineralogy and X-ray Section of the Chemistry Division, D.S.I.R., Building Research Station, Watford.

Dr. Midgley was born at New Malden in 1918, and was educated at Tiffin School, Kingston-on-Thames, and at King's College, London, and Chelsea Polytechnic. After graduating in Geology in 1938, he spent two years as an assistant in the Department of Geology at Chelsea Polytechnic, then during the war he carried out research work with the War Department. He joined the Building Research Station in 1945, and since then he has been investigating the mineralogy of building materials.

H. G. Midgley

**H. R. Tipler, B.Met.**—Research worker in the Metallurgy Division of the National Physical Laboratory, Teddington.

Mr. Tipler was educated at High Storrs Grammar School, Sheffield, and at Sheffield University, where he graduated in 1947. He then took up his present appointment at the National Physical Laboratory, and has since been engaged on an investigation into the effects of alloying elements on the incidence of brittle fracture in high-purity iron.

## IRON AND STEEL ENGINEERS GROUP

### Engineering Committee, 1953–54

The following Members have been appointed to serve on the Engineering Committee :

*Chairman*

| | |
|---|---|
| C. H. T. WILLIAMS | Park Gate Iron and Steel Co., Ltd. |

*Members*

| | |
|---|---|
| J. BAKER | Joseph Booth and Bros., Ltd. |
| T. COXON | Consett Iron Co., Ltd. |
| W. W. FRANKLIN | Davy and United Engineering Co., Ltd. |
| N. R. D. GURNEY | Metropolitan-Vickers Electrical Co., Ltd. |
| T. A. HOGARTH | Llanelly Steel Co. (1907), Ltd. |
| W. A. JOHNSON | United Steel Companies, Ltd. |
| J. A. KILBY | Colvilles, Ltd. |
| P. A. LEE | Arthur Lee and Sons, Ltd. |
| J. A. PEACOCK | John Lysaght's Scunthorpe Works, Ltd. |
| E. PINCHES | Richard Thomas and Baldwins, Ltd. |
| I. S. SCOTT-MAXWELL | Steel Company of Wales, Ltd. |
| A. TAYLOR | Cargo Fleet Iron Co., Ltd. |
| W. S. WALKER | Round Oak Steel Works, Ltd. |
| C. H. WILLIAMS | Stein and Atkinson, Ltd. |
| R. L. WILLOTT | John Summers and Sons, Ltd. |

*Ex-Officio*

| | |
|---|---|
| J. MITCHELL, C.B.E. | President, The Iron and Steel Institute |
| W. BARR | Hon. Treasurer, The Iron and Steel Institute |
| H. R. MILLS | British Iron and Steel Research Association. |

## BRITISH IRON AND STEEL RESEARCH ASSOCIATION

### Annual Report of Council, 1952

The Council of the British Iron and Steel Research Association has presented its Ninth Annual Report for the year ended 31st December, 1952.

The Report states that the progress of the Association's building development at Sheffield has been maintained and that two of the principal laboratories are now completed. At Battersea further alterations and improvements have been made, and at the North-East Coast Laboratories additional space has been acquired. For the first time, the Report contains illustrations of some of the work being carried on in the laboratories, and brief descriptions of the work of each of the Association's Divisions and Departments are given, together with a list of the reports issued during the year. On the whole, more emphasis has been placed on some of the projects that are reaching the stage where development succeeds research, and where member firms take a greater share

in the trial of prototypes and processes which represent the product of the research effort.

Cordial relationships, leading to an exchange of ideas, have been maintained and strengthened with research organizations and corporations in the United States, Canada, and several western European countries. In Holland the Association is represented on an International Joint Committee conducting research on problems of luminous flame radiation and heat transfer, and in Belgium it continues to represent United Kingdom interests in the construction and operation of an experimental low-shaft blast-furnace.

### Conference on Heat-Treatment Practice

The Metallurgy (General) Division of the British Iron and Steel Research Association will hold a Conference on Heat-Treatment Practice at Ashorne Hill, Leamington Spa, from 15th to 17th June, 1953. The Conference will open with an Introductory Talk on the work of the Thermal Treatment Sub-Committee (which is sponsoring the Conference), and will be divided into six sessions : heat treatments of engineering steels, large forgings, and surfaces; surface treatments ; isothermal heat treatment ; and temperature measurement and control. Chairman of the Conference will be Dr. H. H. Burton, C.B.E.

### Appointments

Mr. M. W. THRING has accepted an appointment as Professor of Fuel Technology at the University of Sheffield, in succession to Professor R. J. Sarjant. He will take up his new appointment in October.

Dr. H. R. MILLS has been appointed Head of the Plant Engineering Division of the Association, in succession to Mr. H. H. Mardon.

Mr. C. N. KINGTON, Chief Engineer and Administration Officer at the Sheffield Laboratories of the Association, has in addition been appointed Group Manager. The Laboratories are used by the Steelmaking, Mechanical Working, and Metallurgy Divisions of the Association, and also by the Cutlery Research Council; in his new capacity Mr. Kington is particularly concerned with the relation of this group to the industry, University, and civic authorities of Sheffield, and with the co-ordination of efficient utilization of equipment and resources.

## BRITISH STEEL CASTINGS RESEARCH ASSOCIATION

### Conference on Non-Destructive Testing

The British Steel Castings Research Association held a One-Day Conference on Non-Destructive Testing at the Engineering Centre, Glasgow, on 22nd April, 1953. Its purpose was to present the results of the Association's development work on radiography, and on radiological scanning in particular, and to consider the application both of ultrasonic testing and of xero-radiography in relation to the quality control of steel castings.

## NEWS OF SCIENCE AND INDUSTRY

### Powder Metallurgy Exhibition

Powder Metallurgy Ltd. will hold a Powder Metallurgy Exhibition at the offices of Messrs. F. W. Berk and Co., Ltd., Commonwealth House, 1–19 New Oxford Street, London, W.C.1, on 8th–10th June, 1953. Exhibits will include a comprehensive selection of sintered parts currently used in many engineering industries.

### International Congress of Industrial Chemistry

The 26th International Congress of Industrial Chemistry will be held in Paris from 21st to 27th June, 1953. In connection with the Congress the Société de Chimie Industrielle is holding a chemical exhibition of research work, industrial apparatus, and plastics from 18th to 29th June.

Further particulars may be obtained from the Société de Chimie Industrielle, 28 rue Saint-Dominique, Paris.

### Use of Electrons in the Examination of Metals

A Summer School in " The Use of Electrons in the Examination of Metals " will be held in Cambridge from Monday to Friday, 20th–31st July, 1953. The course will be held in the Cavendish and Goldsmiths' Laboratories and in the Laboratory for the Physics and Chemistry of Surfaces. The administration will be under the control of the Board of Extra-Mural Studies, and the lecturers include Dr. A. F. Brown (Edinburgh University), Dr. V. E. Cosslett (Cavendish Laboratory), Mr. M. E. Haine (Associated Electrical Industries Research Laboratory, Aldermaston), Mr. R. J. Hercock (Ilford Ltd.), Dr. J. W. Menter (Dept. of Physical Chemistry, Cambridge), and Dr. J. Nutting (Dept. of Metallurgy, Cambridge). Further details and application forms may be obtained from the Secretary, Institute of Metals, 4 Grosvenor Gardens, London, S.W.1. Forms must be returned by not later than 13th June, 1953.

### International Congress on Rheology

The Second International Congress on Rheology will be held in Oxford from 26th to 31st July, 1953. In addition to scientific meetings, it is intended to hold the Congress Dinner in the Hall of Christ Church on Wednesday, 29th July, and to arrange a number of excursions for wives accompaning members to the Congress.

### International Union of Pure and Applied Chemistry

The 13th International Congress of Pure and Applied Chemistry (17th Conference of the Union) will be held in Sweden on 29th July–7th August, 1953. The Congress will comprise a Physical Chemistry Section and a Symposium on the Chemistry of Wood and Wood Constituents, to be held in Stockholm from 29th July to 4th August, and a Symposium on Macromolecules, to be held in Uppsala from 5th to 7th August.

### Engineering, Marine, and Welding Exhibition

The next of this series of exhibitions will be held at Olympia, London, W.14, from 3rd to 17th September, 1953.

As in previous years, the Organizers have extended to all Members of the Institute an invitation to visit the Exhibition. Requests for complimentary tickets should be made to the Secretary, 4 Grosvenor Gardens, London, S.W.1.

### Exhibition of X-ray Crystallographic Equipment

The Autumn Conference of the X-ray Analysis Group of the Institute of Physics will be held in London on 20th and 21st November, 1953. An exhibition of X-ray diffraction equipment will be an important feature, and offers of exhibits are invited under two headings : apparatus commercially available in this country, and examples of recent developments in X-ray crystallographic equipment that have been made in universities and other research centres in this country. Offers of exhibits should be submitted before 1st September to the Conference Secretary, Mr. H. J. Goldschmidt, c/o Intitute of Physics, 47 Belgrave Square, London, S.W.1.

### Utilization of Low-Grade Ores

A mission from the Organization for European Economic Co-operation visited Great Britain, France, Germany, Italy, and Sweden last April to gather facts

on research into the exploitation of low-grade ores. It is hoped that, as a result of the mission, there will be closer co-operation between organizations interested in mineral dressing and that methods will be developed for mining and dressing low-grade ores that have as yet been uneconomic to mine.

The mission included experts from Austria, Belgium, France, Germany, Greece, Italy, Norway, Sweden, Turkey, and the United States of America. British representatives were Professor J. A. S. Ritson, and Dr. W. Davies, head of the Ore Dressing Laboratory of the United Steel Companies, Ltd. Secretary of the mission was Mr. J. Sandor, of the Department of Scientific and Industrial Research.

### Physical Metallurgy at Sheffield University

Application for admission to the Postgraduate School in Physical Metallurgy of Sheffield University are invited from :

(a) Scientists already in industry, holding a degree or equivalent qualification, who have had at least three years' experience and wish to pursue more advanced studies in Physical Metallurgy

(b) Recent graduates in Pure Science or Engineering who wish to pursue a metallurgical career.

The fee for a full-time postgraduate course is £50 per annum. Grants for tuition and maintenance are available for suitably qualified candidates. Full particulars may be obtained from the Professor of Physical Metallurgy, The University, St. George's Square, Sheffield, 1.

### Beilby Memorial Award, 1952

The Administrators of the Sir George Beilby Memorial Fund, representing the Institute of Metals, the Royal Institute of Chemistry, and the Society of Chemical Industry, have made an award of one hundred and fifty guineas to :

THOMAS VICTOR ARDEN, B.Sc., F.R.I.C., in recognition of his experimental work on the hydro-metallurgy of uranium, with particular application to the separation of uranium from low-grade ores.

Awards from the Fund are made to British investigators in science as a mark of appreciation of distinguished work, particularly in such fields as fuel economy, chemical engineering, and metallurgy, in which Sir George Beilby's special interests lay. In general, the awards are not applicable to more senior investigators but are granted as an encouragement to relatively young men who have done independent work of exceptional merit over a period of years.

### Faraday Society

The Faraday Society celebrated the Fiftieth Anniversary of its foundation on 16th April, 1953. To mark the Jubilee, a meeting was held at the Royal Institution in the afternoon, followed by a Banquet at the Dorchester Hotel.

### Welding Engineers' and Supervisors' Instruction Courses

The Quasi-Arc Co., Ltd., are holding instruction courses, each lasting three weeks, for welding engineers, supervisors, inspectors, and foremen. About half the time is devoted to technical and theoretical work and half to practical welding experience. The next course will commence on 13th July, 1953, followed by one commencing on 5th October, 1953. Applications for enrolment should be sent to the Quasi-Arc Co., Ltd., Bilston, Staffs., or to Bridgewater House, Cleveland Row, St. James's, London, S.W.1.

## Change of Address

The Leeds Office of RILEY STOKER CO., LTD., has moved to new premises at National Employers House, Quebec Street, Leeds, 1. (Tel. Leeds 33274.)

## CORRIGENDUM

### Presidential Address

The following correction should be made to the Presidential Address by J. Mitchell (*Journal of The Iron and Steel Institute*, 1953, vol. 174, May, p. 6) :

The 3rd paragraph in the L.H. column should commence : " The cost of the 'fuel' in the case of Bessemer steel is, of course, . . . "

## DIARY

**1st–12th June**—SIXTH CANADIAN INTERNATIONAL TRADE FAIR—Exhibition Park, Toronto, Ontario.

**15th–17th June**—BRITISH IRON AND STEEL RESEARCH ASSOCIATION—Conference on Heat-Treatment Practice—Ashorne Hill, Leamington Spa.

**16th–19th June**—AMERICAN WELDING SOCIETY—National Spring Technical Meeting with Welding and Allied Industry Exposition—Shamrock Hotel and Hall of Exhibits, Houston, Texas.

**21st–25th June**—AMERICAN SOCIETY FOR TESTING MATERIALS—Annual Meeting—Atlantic City, N.J.

**21st–27th June**—SOCIÉTÉ DE CHIMIE INDUSTRIELLE—26th International Congress of Industrial Chemistry—Paris.

**24th–26th June**—GROUPEMENT POUR L'AVANCEMENT DES MÉTHODES SPECTROGRAPHIQUES—16th Congress—9 bis Avenue d'Iena, Paris.

**30th June–11th July**—British Instrument Industries' Exhibition—National Hall, Olympia, London.

## TRANSLATION SERVICE

(The previous announcement was made in the May, 1953, issue of the *Journal*, p. 72.)

TRANSLATION AVAILABLE

No 467 (German). E. SENFTER : " The Potential Output of Blast-Furnaces and the Development of the Large Blast-Furnace." (*Stahl und Eisen*, 1952, vol. 72, Dec. 18, pp. 1633–1640).

TRANSLATIONS IN COURSE OF PREPARATION

(German). K. GUTHMANN, P. E. FUNCKE, W. HUNSINGER, C. KREUTZER, W. KELLER, O. STEBEL and W. WISLICENUS : " Roof Temperature Measurement in Open-Hearth and Arc Furnaces with Photo-Electric Pyrometers." (*Stahl und Eisen*, 1952, vol. 72, Nov. 6, pp. 1418–1425).

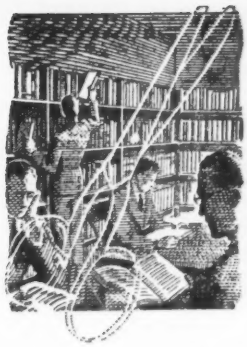
(German). H. SCHUMACHER : " The Operation of the Low-Shaft Blast-Furnace." (Abridged). (*Stahl und Eisen* 1953, vol. 73, Feb. 26, pp. 257–263).

(German). K. GUTHMANN : " The Development of Blast-Furnace Gas Cleaning during the Last Ten Years." (*Stahl und Eisen*, 1953, vol. 73, Feb. 26, pp. 283–292).

CHARGES FOR COPIES OF TRANSLATIONS—The charge for translations is £1 for the first copy and 10*s.* for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether they can be prepared for inclusion in the Series.

# ABSTRACTS AND BOOK NOTICES



IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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## MINERAL RESOURCES

**Iron-Ore Resources : Britain's Present and Future Supplies of Iron Ore Reviewed.** (*Iron Coal Trades Rev.*, 1952, **165,** Nov. 28, 1195–1197). A statistical survey of Britain's present iron-ore resources is given, and future supplies are considered in the light of the industry's development plans.

**Fluorspar.** K. C. Dunham. (*D.S.I.R., Memoirs of the Geological Survey, Special Reports on the Mineral Resources of Great Britain,* vol. 4, 4th edition, London 1952, H.M.S.O.). This 131-page book reports on an investigation of the sources of fluorspar in Great Britain.—R. A. R.

**Tropical Island Iron Ore.** (*Times Rev. of Indust.*, 1953, **7,** Jan., 77). The large iron ore deposits of Cockatoo Island off the North Coast of W. Australia are described. The island is 1500 miles from Perth, and 3000 miles by sea from Port Kembla.—T. E. D.

**The Situation of the Mineral Industry in Morocco.** (*Echo Mines*, 1953, Jan., 53–54). The state of manganese and iron ore mining in Morocco is reviewed.—T. E. D.

## ORES—MINING AND TREATMENT

**Iron-Ore Wagons.** M. D. J. Brisby and R. W. Davis. (*Iron Coal Trades Rev.*, 1952, **165,** Dec. 19, 1343–1345). The authors discuss the development of iron-ore wagons from the old wooden open goods-wagon to the new and projected designs which are to be standardized for operation over the whole country. The 27-ton tippler wagons and 25½-ton hopper wagons are very important additions to the new standard freight rolling stock of British Railways.—G. F.

**Cable Belt Conveyors.** S. H. Gordon. (*Times Rev. of Indust.*, 1953, **7,** Jan. 24–27). The history of continuous mechanical handling is briefly surveyed, and the orthodox belt-conveyor is described. Its advantages over other methods of carrying coal are considered. Its disadvantages, which are numerous, are listed, and the cable belt conveyor, which overcomes many of these, is described with the aid of diagrams.—T. E. D.

**Noise in Mines.** B. Johansson. (*Jernkontorets Ann.*, 1952, **136,** 11, 468–508). [In Swedish]. This is a report of a noise and hearing survey in Swedish iron ore mines carried out during 1949–50. It contains data on : (1) Noise level measurements ; (2) spectrum analysis of noise ; (3) hearing loss measurements on 203 workers ; (4) recovery of hearing after three weeks' holiday ; (5) efficiency of ear protectors ; and (6) speech audiograms of 36 miners.

**The G.E.C. Mineral Dressing Laboratory.** D. G. Armstrong. (*Min. Mag.* 1952,, **87,** Dec., 337–342). The recently reorganized laboratory contains equipment to cover practically the entire range of mineral dressing processes.—K. E. J.

**The Cyclone as a Separating Tool in Mineral Dressing.** K. A. Fern. (*Trans. Inst. Chem. Eng.*, 1952, **30,** No. 2, 82–86). The author discusses the development of cyclones using heavy suspensions for mineral separation, sets out the variables which have been investigated under operating conditions, and discusses the effect of these variables on separations. Results are given of tests carried out with cyclones 3 and 6 in. in dia. on a variety of minerals, and brief reference is made to the cost of cyclone separator plants.—J. C. B.

**A Study of the Motion of Solid Particles in a Hydraulic Cyclone.** D. F. Kelsall. (*Trans. Inst. Chem. Eng.*, 1952, **30,** 2, 87–104). Using an optical method involving suitable ultramicroscopic illumination and a microscope fitted with rotating objectives, tangential velocity components of fine aluminium particles were measured directly at selected positions within a transparent hydraulic cyclone. Vertical velocity components at the same positions were obtained by measuring the angle of inclination of particle tracks to the horizontal, and water radial velocity components were calculated from continuity considerations. Experiments were carried out at indicated feed pressures of 10, 20, 30, and 40 lb./sq. in. The first series involved negligible underflow discharge, the second no overflow, and in the third both underflow and overflow were obtained. The results are presented as tangential, vertical, and radial velocity profiles from which a picture of the flow patterns can be obtained.—J. C. B.

**Iron-Ore Preparation: Latest Methods and Plant in Operation at the Appleby-Frodingham Steel Company.** (*Iron Coal Trades Rev.*, 1952, **165,** Oct. 17, 859–864 ; Oct. 24, 909–915). Extensions to the ore preparation plant at the Appleby-Frodingham Steel Co. are considered, and a detailed description is given of the latest plant and methods used there for crushing, drying, screening, sintering, and mixing the ores. The plant includes a separate system for handling returns ; this is remotely controlled from instrument panels and control houses.—G. F.

**Magnetizing Treatment of Lean Iron Ores.** H. Hendrick and G. Scheibe. (*Arch. Eisenhüttenwesen*, 1952, **23,** Sept.–Oct., 321–324). Experiments have been carried out to determine the best conditions for converting ores containing α-ferric oxide to magnetite or γ-ferric oxide, and so render them suitable for magnetic separation. Solid reducing agents

only were employed. Chemical and X-ray examinations have shown that when α-ferric oxide, intimately mixed with a solid carbon-containing material, is heated to 600–750° C., the active agents affecting reduction to magnetite are organic compounds ; pure carbon is not effective. If the end product is withdrawn from the furnace at a temperature below 220–380° C., it re-oxidizes to γ-ferric oxide. Paraffin wax proved to be the best reducing agent. Ferric oxide previously heated for long periods above 685° C. was not suitable for reduction.—J. P.

**New Results with the Pelletizing of Iron Ore Concentrates.** G. Sengfelder. (*Stahl u. Eisen*, 1952, **72**, Dec. 4, 1577–1579). An experimental plant has been made from a lime kiln, and pellets produced, on a production scale of 12–15 tons/day, with good physical and metallurgical properties. The heat treatment of the moist pellets of limonite in the furnace required an accurately maintained and uniform temperature. The heat losses due to the low height of the kiln were determined and provided useful data for future larger units.—J. P.

**The Permeability of Sinter Beds.** E. W. Voice, S. H. Brooks, and P. K. Gledhill. (*J. Iron Steel Inst.*, 1953, **174**, June, 136–139). [This issue].

**The Chemical Constitution of Sinters.** R. Wild. (*J. Iron Steel Inst.*, 1953, **174**, June, 131–135). [This issue].

**Study on Sintering of Iron Ores. I. Reducibility of Iron Oxide Materials.** Y. Takahashi. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1952, **4**, June, 298–310). [In English]. Briquettes containing $Fe_2O_3$, $SiO_2$ and CaO were heated at 1200 and 1300° C. in air or CO and $CO_2$, and their reducibility at 900° C. was determined. In the samples heated in air, $SiO_2$ and CaO had little effect on reducibility, which varied directly with porosity for the 1200° C. sample. In reducing atmospheres, even small amounts of $SiO_2$ had deleterious effects on reducibility : these were removed when molecular proportions of CaO were also present. No direct relationship with porosity was found. (14 references).—K. E. J.

**Study on the Utilization of Pyrrhotite Principally Composed of Iron and Sulphur. I. On the Roasting of Pyrrhotite.** T. Ishiwara, K. Niwa, and K. Koizumi. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1951, **3**, June, 265–276). [In English]. In attempts to utilize pyrrhotite ores, studies of oxidation velocities and ratios have been made. Optimum conditions for production of hematite cinder and sulphur dioxide appear to be roasting at 700–800° C. for up to 1 hr. The residual cinder is suitable for iron making, containing $<0{\cdot}2\%$ sulphur.

**Study on the Utilization of Pyrrhotite Principally Composed of Iron and Sulphur. II. On Making Sulphuric Acid from the Roasting Gases of Pyrrhotite.** T. Ishiwara, K. Niwa, and K. Koizumi. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1951, **3**, June, 277–280). [In English]. Pyrrhotite ore of 28–32 mesh size, was roasted at 700° C. in a small rotary furnace, the gases being converted into sulphuric acid by the contact process. Most favourable conditions were when $SO_2$ concentration was $7{\cdot}7{\cdot}5\%$, and the catalyst temperature approx. 440° C. After 30–48 hr. roasting, the residual oxide cinder contained only $0{\cdot}2{\text-}0{\cdot}4\%$ sulphur.—K. E. J.

**Who Will Supply Power for Processing Taconite?** (*Eng. Min. J.*, 1952, **153**, Dec., 103, 118). An estimated minimum of 600,000 kW. generating capacity will be required for processing taconite on the Mesabi range : power needed is estimated at 100 kW./ton for beneficiation. Details are given of four projected major installations.—K. E. J.

**Taconite New Source of Iron Ore.** M. M. Hunt. (*Echo Mines*, 1952, Nov., 718–720). A brief survey is given of the work of enriching and agglomerating taconite ore.—T. E. D.

**Note on the Agglomeration of Ores and Blast-Furnace Flue-Dust.** R. Godiniaux. (*Arts et Manuf.*, 1953, Jan., 34–35). A brief outline is given of the principal features of Dwight Lloyd, Greenwalt, and A.I.B. sinter plants. The Schmidt kiln type of agglomeration plant is also mentioned.—T. E. D.

## FUEL—PREPARATION, PROPERTIES, AND USES

**Rates of Combustion of Solid Fuel Particles.** G. A. E. Godsave. (*Nature*, 1953, **171**, Jan. 10, 86). The calculation of the mass transfer of oxygen to solid burning spherical surfaces by means of a semi-empirical equation due to Frössling is discussed. For carbon spheres at a mean gas film temperature of 1200° C. the equation is $F = 0{\cdot}347\ (1 + 0{\cdot}272\ Re^{\frac{1}{2}})$ where $F$ is a non-dimensional reaction rate factor. Good agreement with experimental results is reported.—A. G.

**Flame Radiation Trials at the Royal Netherlands Steelworks.** (*Blast Furn. Steel Plant*, 1952, **40**, Dec., 1465–1466, 1468). A short account of an international investigation into the luminous radiation of flames, which is being carried out in Holland, is given. Experiments with oil fuels are complete, those with gas are in progress and those with solid fuels are to follow. The results obtained with oil fuels are summarized. The difference between various burners was found to be unimportant compared with the effect of variation in the quantities of atomizing agents.—B. G. B.

**Luminous Flame Increases Heat Transfer.** (*Steel*, 1952, **131**, Sept. 1, 94–97). A review of the research work being carried out at the Royal Netherlands Steelworks is given. Results show that the radiation in the early part of the flame is mainly affected by a change of fuel or atomizing agent, whereas the tail of the flame is affected by the quantity of fuel, atomizing agent and combustion air. The radiation in the early part of the flame thus depends on the rapidity of ignition.—A. M. F.

**The Optics of Luminous Flames.** W. Pepperhoff and A. Bähr. (*Arch. Eisenhüttenwesen*, 1952, **23**, Sept.–Oct., 335–344). The optical properties of luminous flames obey Beer's absorption law. The absorption constants exhibit (as a result of diffraction of light by the fine soot particles suspended therein) a marked dependence on wavelength which is proportional to $\lambda^{-n}$ in the visible and to $\gamma^{-(n-m \log \lambda)}$ in the infrared ranges. The constant $n$ is a function of the mean diameter of the soot particles. This behaviour is analogous to that of a colloidal system, and permits the treatment of the properties of flames by the theoretical optics of turbid media. The values calculated by Mie's theory are in good agreement with experiment. Calculation of the radiation efficiency of luminous flames shows the important influence of the degree of division of the soot; at equal true flame temperature and soot concentration, flames with finely divided soot radiate considerably more energy than those with coarse particles. From a few measurements of colour and black body temperatures of the flames, the spectral radiation density and the total radiation can be calculated. A diagram illustrating the connection between these is given. Moreover, results obtained by use of Mie's theory allow the simple optical measurement of soot particle size and soot concentration.—J. P.

**Physical Basis of Flame Photometry.** J. A. Smit. (*Chemisch Weekblad*, 1952, **48**, Sept. 20, 697–699). [In Dutch].

**Evolution and Combustion of Volatile Matter from Coals. Part III—Combustion and Related Factors.** J. R. Arthur and D. H. Napier. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1952, **16**, July, 309–319). This review surveys present knowledge on the subject and concludes that more information is necessary before the mechanisms of volatile emission and combustion can be detailed.—D. L. C. P.

**Developments in the B.C.U.R.A. Dew-Point Meter, for the Measurement of the Rate of Acid Build-up on Cooled Surfaces Exposed to Flue Gases.** P. F. Corbett, D. Flint, and R. F. Littlejohn. (*J. Inst. Fuel*, 1952, **25**, Nov. 246–252).

**The Measurement of Combustion Losses.** D. C. Gunn. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1952, **16**, Sept., 397–403). The author reviews instruments available for taking relevant measurements. Instruments for continuous measurement of heat loss in ashes have been developed but not extensively applied. More study of gas sampling techniques is required, but analysis instruments have received considerable attention. Several new approaches to fluid flow measurements are mentioned.—D. L. C. P.

**Re, Pr, Nu, St, Pe . . . . What's their Real Significance ?** J. J. Carberry. (*Chem. Eng.*, 1952, **59**, Sept., 144–148). The most important dimensionless groups used in correlating heat transfer data are defined. The derivations of the Reynolds, Nusselt and Prandtl numbers are made, and examples of their uses are given.—T. E. D.

**A Gauge for Indicating Pressure Transients in a Combustion Chamber.** H. D. Warshaw. (*Rev. Sci. Instruments*, 1952, **23**, Sept., 493–496). This instrument is primarily designed for measuring pressure changes within a gun barrel, but could be adapted for other combustion chambers. Its construction is described.—L. H.

**Extended Surfaces for Heat Exchangers.** (*Engineering*, 1952, **174**, Dec. 12, 745–747). This article describes heat exchanger apparatus in which efficiency is obtained by means of extended surfaces obtained by welding small copper rods to the surface of the heating tube. The shape and size of these rods determine the success of the system.—M. D. J. B.

**Sulphur Coal of Istria.** D. J. W. Kreulen. (*Fuel*, 1952, **31,** Oct., 462–467). The properties of the Rasa coal of Istria, which exhibits a dual character (some properties indicating low rank, others a high rank), are discussed.—B. G. B.

**Guide to Coal Sampling.** J. Visman and P. G. Meerman. (*Chemisch Weekblad*, 1952, **48,** Aug. 23, 605–611). [In Dutch]. From the coal characteristics, three 'sampling constants' are derived. These are : (1) Dependent on the random nature of sampling ; (2) dependent on segregation ; and (3) defined by sample reduction and analysis. The determination of these constants, and the sample weight and number of increments is facilitated by nomograms. Sample collecting and reducing techniques are described in detail.

**The Cost of Coal Preparation.** S. Flehmig. (*Glückauf*, 1953, **89,** Jan. 17, 72–76). In the light of revised wages and costs in Germany since 1950, a costing analysis is made, in which the cost is broken down into separate stages of preparation, and then subdivided in detail.—L. H.

**The Design and Application of Wet Centrifugal Separators for Coal Preparation.** E. Hoffmann. (*Glückauf*, 1953, **89,** Jan. 31, 105–120).

**Gig Washers in Theory and Practice.** A. A. Hirst. (*Colliery Guardian*, 1952, **186,** Feb. 5, 157–161).

**The Random Breakage of Coal and Its Assessment.** S. Guruswamy. (*J. Sci. Indust. Res.*, 1952, **11,** Nov., B482–B485). It has been found that for the breakage of coal in the shatter test, the relation between size and weight of the broken product can be given by $S = K \cdot P^n$ where $S$ is the linear mean size, $P$ the weight-% of the broken coal, and $K$ and $n$ are constants. The factor (K.100/initial size) is called the 'toughness factor' and it is used to compare the breakability of coals.—E. T. L.

**On the Manufacture, Distillation and Smelting of Iron-Rich Coke for Lean Gas Manufacture.** H. Barking and C. Eymann. (*Glückauf*, 1952, **88,** Nov. 8, 1090–1094 : *Iron Steel Inst. Translation Series* No. 459, 1953). Laboratory and large-scale experiments are described, in the production of iron-rich coke by the coking of a mixture of high volatile coal and iron ore fines and flue dust. Iron contents of 30–50% are mentioned ; the physical properties compare well with normal blast-furnace coke. With the exception of ammonia, a normal yield of by-products is obtained. After a general description of the properties of the coke, the author refers to a process of pig iron production, in which the burden consists of iron-coke, lump iron ore, and fluxes ; the iron produced is suitable for the open-hearth furnace. The possibility is discussed of the generation, at the same time, of a lean gas suitable for heating coke-oven batteries.—L. H.

**Assessment of Coals for Coking.** J. H. McKee. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1952, **16,** Feb., 41–51). In addition to surveying the tests which have been used for assessing the coking behaviour of coals, this review considers the factors involved in blending, and the desirable properties of metallurgical coke. (74 references).—D. L. C. P.

**Studies of the Extraction and Coking of Coal and Their Significance in Relation to Its Structure.** M. Orchin, C. Golumbic, J. E. Anderson, and H. H. Storch. (*U.S. Bur. Mines, Bull.* 505, 1951, 1–15). A study of the solvent extraction of some U.S. coals at high temperatures (up to 400° C.) at atmospheric pressure is described. Infra-red absorption spectra and X-ray diffraction patterns of extracts are shown. The coking properties of fractions were studied. The effect of various treatments, and the addition of inorganic salts on coking properties are also mentioned. (24 references).—T. E. D.

**Influence of Iron Oxide on the Reactivity of Low Rank Coals from Collie, Western Australia.** R. P. Donnelly, R. Broadbent, and B. J. O'Leary. (*Fuel*, 1952, **31,** Oct., 418–428). The reactivity of pre-lignitous coal is low when iron oxide is absent from the intrinsic ash, but high where it is present. Iron oxide in the extraneous ash has no effect.—B. G. B.

**Influence of Certain Inorganic Matter, Fusain and 'Dull' Coal on the Free Swelling Index of Coal.** R. Q. Shotts. (*Fuel*, 1952, **31,** Oct., 448–461). The effects on the free swelling index of coals, of dilution with varying quantities of high-density fractions of the coals, quartz, shale, ignited shale, fusain, vanadium pentoxide, ammonium chloride, and boron oxide have been studied. The results obtained are discussed.

**A New Product from Benzene and Blast-Furnace Gas.** J. L. Boyle. (*Blast Furn. Steel Plant*, 1952, **40,** Dec., 1443–1447). The author proposes a process for the manufacture of benzaldehyde from benzene and carbon monoxide in blast-furnace gas. The reaction occurs under pressure (500 atm.) in the presence of aluminium chloride. Details of the process are given.

**The Variation of Carbon Dioxide Reactivity of Cokes During Its Determination.** H. Guérin and L. Hosti. (*Compt. Rend.*, 1952, **235,** Dec. 1, 1400–1402). Tests on five cokes at 1250° C. show a rapid increase in reactivity up to 5% consumption of coke followed by a period of more or less constant reactivity. These results, and others at 950° C., classify the cokes in the same order of initial reactivity. Fuller information would be given by an integral reactivity from the time reaction begins until only clinker remains.—A. G.

**Leveller Bars and Agitators for Gas Producers.** S. A. Burke and G. A. Sparham. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1952, **16,** Aug., 349–366). The authors review the principles underlying the design of leveller bars and agitators, and give examples of the various types with an estimate of their efficiency. (42 references).—D. L. C. P.

**The Composition of Producer Gas from Coals.** E. Schwarz. (*Radex Rundschau*, 1948, No. 3–4, June, 41–48). A diagram is developed permitting the graphical evaluation of the composition of producer gas from coal, similar to one developed earlier for gas from coke. Practical examples are quoted showing the application of the diagram for gas control.—E. C.

**Cleaning of Gases.** B. Dostál. (*Strojírenství*, 1952, **2,** 11, 517–519). [In Czech]. This is a survey and discussion of methods suitable for the purification of gases used in industrial processes.—P. F.

**Physico-Statistical Principles of Gas Cleaning.** F. Magyar. (*Radex Rundschau*, 1948, No. 1–2, Apr., 3–8). The possibilities of statistical assessment of the performance of gas cleaners are discussed in general terms. Physical principles of filters are considered in two groups, with axial and radial gas flow respectively. The scope and limitations of mathematical treatment of filter efficiency are outlined.—E. C.

**Removal of Sulphur Oxides from Flue Gases.** P. F. Corbett and R. F. Littlejohn. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1952, **16,** Oct., 437–443). The authors review this problem from the economic, social, and technical aspects. Flue gas treatment available at present is only a practical proposition for large plants. (53 references).—D. L. C. P.

**The Use of Methane in Industrial Furnaces.** F. Roma. (*Calore*, 1952, **23,** Dec., 592–597). [In Italian]. The author briefly reviews the calorific properties of methane gas and types of furnaces in which methane can be used successfully. The possibilities of using this gas in open-hearth steelmaking furnaces are discussed, and it is claimed that methane enriched with small quantities of oil is entirely satisfactory.

**The Combustible Properties of Mine Gases and the Safety Precautions Necessary When Burning It.** A. Sauermann. (*Glückauf*, 1952, **88,** Nov. 22, 1162–1164). The properties of the gas are first outlined. Owing to its high methane content, its calorific value is about double that of an average coke-oven gas but the amount of waste gas is much higher, and specially designed burners are necessary. The ignition velocity of mine gas is low, but can be increased.—L. H.

## REFRACTORY MATERIALS

**The Magnesite Deposits on the Millstätter Alp near Radenthein (Carinthia).** A. Awerzger and F. Angel. (*Radex Rundschau*, 1948, No. 5–6, Aug., 91–95). The geology and structure of the deposits are described and reserves are quoted.

**40 Years' Existence of the Radenthein Magnesite Works.** O. Büchler-Hauschka. (*Radex Rundschau*, 1948, No. 5–6, Aug., 79–80). A brief survey is made of the development of this company.—E. C.

**Development of Production at the Works of the Österreichisch-Amerikanische Magnesit A.G.** K. Konopicky. (*Radex Rundschau*, 1948, No. 5–6, Aug., 81–83). The production of sintered magnesite, magnesite, and chrome magnesite refractories up to 1937 and in 1947 is briefly surveyed.—E. C.

**The Commercial Development of the Magnesite Industry.** E. Bargezi. (*Radex Rundschau*, 1948, No. 5–6, Aug., 84–87). The development of the international magnesite industry is surveyed, with particular reference to the part played by the Radenthein magnesite works.—E. C.

**Fused Magnesia.** P. Lanser. (*Radex Rundschau*, 1948, No. 5–6, Aug., 96–97). Possibilities of using electrically fused magnesia for the production of high-purity and high-density refractories are described. Considerably improved properties are obtained as compared with sintered magnesia. High

resistance to thermal shock and absence of shrinkage cracking would justify the higher production costs for specialized uses.

**The Production of Magnesium Oxide from Carnallite Mother Liquor.** M. Orman. (*Prace Inst. Metalurgii*, 1952, No. 4, 293–301). [In Polish]. The use of a carnallite mother liquor left after removal of potassium chloride for the production of magnesium oxide suitable for making magnesite refractories was investigated on a laboratory scale.—V. G.

**Chemical and Mineralogical Constitution of Magnesite Refractories.** K. Konopicky and F. Trojer. (*Radex Rundschau*, 1947, No. 1–2, June, 3–15). Data and information scattered in the literature are collected and partly supplemented in a discussion of phase equilibria in magnesite refractories. Chemical and mineralogical properties are quoted for MgO, CaO, magnesium ferrite, forsterite, monticellite, merwinite, di- and tri-calcium silicate, and dicalcium ferrite.—E. C.

**Microscopic Investigations on a Thermal-Shock Resistant Magnesite Brick.** F. Trojer. (*Radex Rundschau*, 1948, No. 5–6, Aug., 98–101). A Radex-A magnesite brick was subjected to 1000 chillings. Polished and thin sections from the brick were examined microscopically and its mineralogical composition and microstructure are described and discussed.

**Sampling and Quality Control.** E. H. M. Badger. (*Gas Times*, 1952, **73**, Nov. 28, 307–308). Statistical methods of sampling and of inferpreting quality control tests are discussed. Particular attention is paid to the methods of 'experimental design', many of which were developed by R. A. Fisher in connection with soil fertilizers. As an example of their application, an account is given of an investigation into the reheating test for firebricks carried out in two different laboratories.—T. E. D.

**Observations on Experiments on the Collapse of Refractory Products under Load at High Temperatures.** J. Baron. (*Silicates Indust.*, 1952, **17**, Oct., 285–289; Nov., 340–343). Results of strength tests on magnesia, silica, and chrome-magnesite refractories at temperatures up to their respective melting points, are reported and discussed. The experiments were carried out with standardized French testing equipment. With more precision in some of the standards, results reproducible from laboratory to laboratory should readily be obtained.—P. F.

**Some Properties of Refractories Based on Alumina and Vanadium Sesquioxide.** M. Foex. (*Silicates Indust.*, 1952, **17**, Nov., 326–329). Relations between composition, heat-treatment, electrical conductivity, and their dependence on temperature in $V_2O_3$ and $Al_2O_3$ base refractories are discussed.

**Some Uses of Silicones in the Manufacture of Heat-Resisting Materials.** P.-H. Morel. (*Métaux–Corrosion–Indust.*, 1952, **27**, Dec., 511–514). A number of uses of products based on silicones which are stable up to 300° C. are described.—B. G. B.

**Fundamental Considerations Relating to the Use of Special Basic Bricks in the Metallurgical Industry.** L. Hütter. (*Radex Rundschau*, 1948, No. 5–6, Aug., 116–122). The various causes of wear and breakdown of refractory bricks in open-hearth furnaces are surveyed. Improvements obtained through the introduction of chrome-magnesite refractories are discussed, and a number of special compositions are considered with a view to high resistance to temperature changes and absence of shrinkage and cracking. Grain size and size distribution in the mixture are important factors. Structural changes necessitated by the use of special bricks are described, also improvements in burner construction.—E. C.

**The Development of Magnesite Bricks as Reflected by Patents.** K. Konopicky. (*Radex Rundschau*, 1948, No. 5–6, Aug., 107–115). The development of methods and techniques of producing magnesite refractories is described in a survey of the world patent literature, a list of the 182 patents being appended.—E. C.

**Calculation of Furnace Roofs and Roof Bricks.** (*Radex Rundschau*, 1948, No. 3–4, June, 64–65). A number of simple formulæ for roof and brick shapes, for use in maintenance and repair work, are given.—E. C.

**The Basic Open-Hearth Furnace Roof.** L. Hütter. (*Radex Rundschau*, 1947, No. 1–2, June, 16–23). Fundamental principles and general development of basic roofs for open-hearth furnaces are described. The Radenthein type of hanging roof is discussed in detail and standardized brick data are quoted.—E. C.

**Chrome-Magnesite Refractories in the All-Basic Open-Hearth Furnace: Their Constitution and Performance.** (*Iron Coal Trades Rev.*, 1952, **165**, Sept. 26, 697–700). The present position regarding the application and performance of chrome-magnesite refractories in all-basic melting furnaces is reviewed The constitution and properties of the bricks are discussed, and particular attention is drawn to the iron oxide expansion causing bursting, which is the most serious defect encountered in service.—G. F.

**A New Type of Lining for Rotary and Drum Furnaces.** R. Maurer. (*Radex Rundschau*, 1947, No. 1–2, June, 29–31). A new type of lining construction based on the use of rhombic bricks is described and claimed to be very simple and efficient. A table of brick dimensions is included.—E. C.

**Chrome Magnesite Bricks Resistant to Thermal Shock for the Construction of Open-Hearth Furnaces.** O. Krifka and A. Schöberl. (*Radex Rundschau*, 1948, No. 3–4, June, 57–60). An account is given of operational experience and advantages obtained after replacing silica roofs and magnesite linings with chrome magnesite bricks of the type Radex E. Heat consumption, hourly output, and furnace life were considerably improved. Metallurgical advantages are also claimed.—E. C.

## BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

**Progress in Ironmaking.** A. Mercier. (*Arts et Manuf.*, 1953, Jan., 29–32). Post-war progress in France of blast-furnace construction and auxiliary plant is briefly reviewed.

**Turbo-Blowers in Blast-Furnace Plants.** M. Haller. (*Brown Boveri Rev.*, 1952, **39**, May–June, 189–199). A brief outline of blast-furnace operation is followed by a discussion of the regulation of the blast-furnace blower for various operating conditions. The most important features of a new axial-flow blower are also discussed.—T. E. D.

**Primary Records in the Iron and Steel Industry, with Particular Reference to Blast-Furnace Operation.** G. Prieur and O. M. Petersen. (*Stahl u. Eisen*, 1952, **72**, Dec. 18, 1665–1671). The development of systems of organization for establishing primary records is considered on the basis of investigations in iron and steel plants. Using blast-furnace operation as an example, primary records are discussed according to type and content, and their action on the setting up of a quantity structure is studied.—J. P.

**The Low-Shaft Blast Furnace: Present Situation in Development of a New Ironmaking Unit.** T. E. Dancy. (*Iron Coal Trades Rev.*, 1952, **165**, Sept. 26, 689–692). The author surveys the present state of knowledge on smelting in low shaft blast furnaces. Mention is made of the Tysland-Hole electric furnace, the use of a briquetted charge and oxygen-enriched blast, and of a combination of low-shaft blast-furnace and gas producer. The planning of experimental work on this type of furnace by an international committee is outlined. Finally, future trends in low-shaft smelting are suggested.

**International Research on the Low Shaft Furnace.** Steering Committee of the International Committee on Low Shaft Furnace Research. (*Rev. Mét.*, 1952, **49**, Oct., 741–746). The principal applications of low shaft furnace smelting are outlined and the need for further research emphasized. The organization of the International Committee controlling this research is outlined. Technical details of the experimental plant under construction in Liége, Belgium, and administered by the Committee, are given together with the chief characteristics of the low shaft furnace itself.—A. G.

**No Drastic Change Seen in American Blast-Furnace Design.** O. R. Rice. (*Steel*, 1952, **131**, Oct. 20, 104–119). Current trends in the layout and ancillary equipment of American blast-furnaces are described. Attention is being given to the crosswise casthouse arrangement, and amongst other items more equalizer and relief control equipment is coming into use, stoves are being given larger combustion chambers, and the surface cooling of boshes is being considered.—A. M. F.

**Furnaces—Trends in Design and Operation.** F. H. Slade. (*Iron Steel*, 1952, **25**, Dec., 523–526). The author traces developments in the design and operation of iron and steel furnaces which have been effected in the last decade to keep pace with the need for increased production. Blast-furnaces, rocking and rotary furnaces, and high-frequency furnaces are the main types considered and mention is made of the provision of dry blast, the use of oxygen, and fume removal.—G. F.

**Tubular Construction Skip Bridge for Blast Furnaces.** (*Engineering*, 1952, **174**, Dec. 5, 722–723). **Construction of a Tubular Steel Skip Bridge.** (*Engineer*, 1952, **194**, Dec. 19, 831–832). **Skip Bridge, Bilston.** (*Colliery Guardian*, 1952,

**185,** Dec. 18, 742–744). **All-Welded Skip Bridge.** (*Iron and Steel*, 1953, **26,** Mar., 99–100). Particulars are given of a novel design, based on welded steel tubes, of a skip bridge erected for a new blast-furnace at the Bilston works of Stewarts and Lloyds, Ltd. The bridge box section is 13 ft. wide × 12 ft. high ; the length is 140 ft. and the weight only about 30 tons.—R. A. R.

**Operation of Metallurgical Reduction Furnaces by ' Airless ' Working.** L. Pottecher. (*Rev. Mét.*, 1952, **49,** Nov., 811–814). A scheme is suggested whereby carbon monoxide is taken from the stack at about 700° C. Above this level air is injected to burn the remaining carbon monoxide and pre-heating the charge. A mixture of CO, $CO_2$ and pure oxygen is blown in at the tuyeres, enabling tuyere temperature to be controlled. In a modern plant, production with oxygen would consume 175 kWh/ton of iron, this being offset by lower blowing costs, absence of hot blast stoves, and increased production.—A. G.

**The Efficiency of Blast-Furnaces and the Path to the Development of Large Blast-Furnaces.** E. Senfter. (*Stahl u. Eisen*, 1952, **72,** Dec. 18, 1633–1640: Iron Steel Inst., 1953, *Translation Series* No. 467). There is a trend towards blast-furnaces with 1000–2000 tons/day output. The construction of such furnaces demands a knowledge of the relationship between output and furnace dimensions for the different types of burden. Investigations of efficiency, expressed as daily throughput of coke, have shown that hearth diameter, furnace volume, and throat cross-section increase with output. The throat diameter therefore increases only as the square root of the output. Hearth diameter therefore increases at a faster rate than does throat diameter. The profile for a coke throughput of 1000 or 2000 tons/day is thus a squat, heavily tapered, truncated cone, and no danger is to be expected of non-uniformity of gas flow and heating of the charge. To change existing large blast-furnaces to the approved profile, it is necessary to raise the hearth efficiency so that the diameter can be reduced and thus, with fixed furnace cross-section and throat diameter, make possible a slender profile. The necessary increased efficiency can be obtained partly by increased blast pressure. The process is, however, too expensive in plant and operating costs. To increase output in spite of low blast pressure, it is recommended that two or more superimposed sets of tuyeres should be installed so as to enlarge the active combustion zone. This should make possible the use of blast-furnaces with 2000 tons/day output even from lean ores.—J. P.

**Seventy-one Years of Blast Furnacing at South Works.** H. E. Kaufman. (*Blast Furn. Steel Plant*, 1952, **40,** Dec., 1457–1464). Blast-furnace operation commenced in 1881 at the South Works of the U.S. Steel Company, and the author reviews the development of the works to the present day. Hearth diameters have increased from 9 to 28 ft., the transition being very gradual. The production rate of individual blast furnaces has increased at an average rate of 100 tons/day/decade and this increase closely follows the increase in hearth diameter and blowing rates. During the first 60 years the coke rate declined at an average rate of 80 lb./ton/decade. During the last 10 years the coke rate has risen 200 lb./ton due to deterioration in coke quality and increased ore fineness.

**Some Aspects of Blast-Furnace Practice.** J. S. Blair. (*Proc. Ebbw Vale Met. Soc.*, 1952, **2,** 17–28). The author describes the blast-furnace process, the fundamental reactions involved, and discusses difficulties with which the blast-furnace operator has to contend in his efforts to make a desirable product.—J. C. B.

**Blast Furnace Charging.** (*Times Rev. Ind.*, 1953, **7,** Feb., 24–27). The use of a covered conveyor belt instead of skips for charging two, and later three, blast furnaces at the Seraing Works, Liége, Belgium, of S.A. John Cockerill is described.—T. E. D.

**Relining and Enlarging No. 9 Blast-Furnace at Appleby-Frodingham.** G. D. Elliott, A. Bridge, E. Jarvis, and T. E. Mitchell. (*J. Iron Steel Inst.*, 1953, **174,** June, 143–158). [This issue].

**Investigations of the Blast-Furnace Combustion Zone : High-Speed Film Camera Technique.** (*Iron Coal Trades Rev.*, 1952, **165,** Nov. 21, 1143–1144). A brief description is given of British and American research work, using stereoscopic and normal ciné-photography respectively, into the activity in the tuyere zone in a blast furnace. It is concluded that a vertical raceway exists in front of each tuyere with the blast roughly tangential to the lower edge, and a tentative explanation of the mechanism of hanging and slipping in the furnace is put forward. Model work which supports these points is described.—G. F.

**Size Distribution as a Quality Factor of Blast-Furnace Coke.** J. Taylor and J. D. Gilchrist. (*Iron Coal Trades Rev.*, 1952, **165,** Nov. 7, 1023–1026). The size of coke approaching the tuyere zone of a blast-furnace is affected by many variables both inside and outside the furnace. The authors have carried out experiments to determine the effect of the strength of coke, and of its treatment by various handling systems, on the size distribution. Results are presented, but the complexity of the blast-furnace process prevents any firm conclusions being drawn.—G. F.

**Stoichiometric Analysis of the Blast-Furnace Process.** W. Kuczewski, W. Dragan, and K. Moszoro. (*Hutnik* (Katowice), 1952, **9,** 11, 377–382). [In Polish]. On the basis of stoichiometric calculations, the factor $Z$ was established which represents the kilogrammes of carbon taken up by $CO_2$ from the decomposition of carbonates per 100 kg. of pig iron. Examples of operating data in two groups with positive and negative $Z$ factors respectively, are cited. All efficiently working modern blast-furnaces fall in the negative $Z$ group, *i.e.*, with a well-pronounced carbon deposition reaction, producing carbon in quantities higher than those necessary for the carburization of the pig. Three kinds of ore reduction are differentiated : (1) Gaseous or indirect reduction ; (2) reduction of the ore with deposited carbon ; and (3) reduction of slag with carbon in liquid iron and ore with solid carbon of the coke. Some other factors influencing coke rate are briefly discussed.—V. G.

**A Study of the Chemical Compositions of Some Spanish Iron Ores.** M. Salis Martinez, L. Barron del Real, J. de Figueras y Figueras, and E. Charro Sanchez. (*Inst. Hierro Acero*, 1952, **5,** Oct., 977–1019). [In Spanish]. Sixty-one Spanish ores are studied. The authors compare various types of reduction which are determined by their chemical compositions. Approximate coke consumptions for smelting the ores are stated.—R. S.

**What Smeltermen Should Know About Automatic Furnace Control.** L. Walter. (*Eng. Min. J.*, 1952, **153,** Oct., 96–100). Automatic control should only be applied to furnaces after optimum operating conditions have been established. The economic factors involved are discussed, and descriptions are given of the principles and characteristics of available systems (' on-off ', floating, proportional, and reset systems, and modifications and combinations of these).—K. E. J.

**On the Equilibrium among Silicon in Molten Iron Blast Furnace Slag and $H_2$–$H_2O$ Mixed Gas. I.—Measurement of the Equilibrium among Silicon in Molten Iron, $SiO_2$–CaO Binary Slag and $H_2$–$H_2O$ Mixed Gas.** K. Sanbongi and M. Ohtani. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1952, **4A,** Feb., 59–71). [In English]. Measuring the equilibrium of $(SiO_2)_{sat} + 2H_2 \rightleftharpoons Si + 2H_2O$ in the range 1500–1600° C., the authors found the relation

$$\log K^{S}_{Si\text{-}H} = \log\left(\frac{p^2_{H_2}}{p^2_{H_2O} \times Si}\right) = \frac{12{,}800}{T} - 3{\cdot}62.$$

They also determined the equilibrium for the reaction $(SiO_2)_{CaOsat} + 2H_2 \rightleftharpoons Si + 2H_2O$ in the range 1550–1650° C., and calculated the activities of $SiO_2$ at three temperatures. Combining these data with those for $\alpha SiO_2$ in $SiO_2$–CaO binary slag reported by Chang and Derq, the authors performed the thermodynamical calculation for the molten $SiO_2$–CaO binary slag and established the equilibria for silicon in molten iron, molten $SiO_2$–CaO slag, and $H_2$–$H_2O$ mixed gas.

**A Method for the Study of Gas-Solid Reactions—Application to the System Iron–Carbon–Hydrogen.** L. Beaujard, G. Collette, and L. Jacqué. (*Compt. Rend.*, 1952, **235,** Dec. 1, 1388–1390). An apparatus incorporating a continuous magnetic balance is described. By adjusting gas composition until constant specimen weight is attained, the equilibrium value for the reaction C in $\gamma Fe + 2H_2 \rightleftharpoons Fe + CH_4$ has been determined and compared with calculated values of Austin and Day.—A. G.

## TREATMENT AND USE OF SLAGS

**Studies on the Melilite Solid Solutions.** R. W. Nurse and H. G. Midgley. (*J. Iron Steel Inst.*, 1953, **174,** June, 121–131). [This issue].

**Investigations of the Solubility of the Phosphoric Acid in Basic-Bessemer Slags.** S. Gericke. (*Stahl. u. Eisen*, 1952 **72,** Dec. 4, 1580–1583). Increasing the silica content and $SiO_2/P_2O_5$ ratio in basic phosphates increases the solubility of the phosphoric acid in citric acid. The effect of silica on the solubility in ammonium citrate is similar though the latter is more markedly affected than the citric acid solubility by such factors as cooling rate and structure of the slag. The combination of silica in the phosphate complex is a requisite for a readily decomposable compound with a high physiological activity. The silica and total lime contents of basic-Bessemer slags are not closely related.—J. P.

## PRODUCTION OF STEEL

**Developing Increased Capacity at Armco's Middletown Division.** G. D. Tranter. (*Iron Steel Eng.*, 1952, **29,** Nov., 90–96). The new installations at the Middletown Division of Armco, and the sequence in which a programme is being carried out to provide a well-balanced operation of steel melting, rolling and finishing capacities are described. Details are given of the Sendzimir coating process, the electric melting and open-hearth departments, the hot strip mill, blast-furnaces, and coke ovens.—M. D. J. B.

**Fairless Works.** (*Steel*, 1952, **131,** Sept. 22, 122–144). An extensive description is given of the Fairless Works of the United States Steel Co., Morrisville, Pa. The initial plant capacity is 1·8 million tons of ingots per year.—A. M. F.

**Anor Steel Works and Forges.** (*Aciers Fins Spec. Franç.*, 1951, Nov. 43–45). The article deals briefly with the history, present-day layout, and production at the Anor Works. Production includes blades for many industrial uses ; machines for surfacing, grinding, bevelling and sharpening all types of straight blades from 1 to 6 m. long ; and forgings and castings from special steels.—E. C. S.

**Saint-François Steelworks and Forges.** (*Aciers Fins Spec. Franç.*, 1952, Dec., 95–96). A brief account of the history and the products of this French company is given. Tool and other special steels are made in induction furnaces.—R. A. R.

**Blowing Basic-Bessemer Iron with a Free Jet.** C. V. Schwarz. (*Stahl u. Eisen*, 1952, **72,** Dec. 18, 1642–1649). Experiments have been carried out in an electric arc furnace to ascertain whether oxygen-enriched air, top-blown through a free jet to obtain greater penetration, could be used to produce a low nitrogen steel. The design of the jet, its optimum diameter and height above, and inclination to, the bath surface were determined. It was found that steels could be produced with less than 0·0045% nitrogen and that cooling with mill-scale was very effective ; much of the oxide was reduced to iron. Dephosphorization before the end of the carbon period was not possible because a fluid slag could not be obtained early enough. The utilization of the oxygen was as high with the free jet as when oxygen lances are used.—J. P.

**The Refining of Basic-Bessemer Pig Iron with Pure Oxygen.** F. A. Springorum, K. G. Speith and W. Oelsen. (*Stahl u. Eisen*, 1953, **73,** Jan. 1, 6–19). Tests with a basic 3-ton converter showed that pig iron with about 2% P can be satisfactorily top-blown with pure oxygen and that, by correct choice of additions, oxygen pressure, temperature and slag composition, a product equal to open-hearth steel can be produced. Scrap or ore must be added for cooling. When scrap is added the process is similar to that with air-blowing, and phosphorus is not adequately removed by the end of the carbon period ; an after-blow amounting to 30–50% of the total blowing time is required. With top-blowing and ore additions it is possible to reduce phosphorus below 0·07% by the end of the carbon period and yet have low iron in the slag and a final temperature high enough for satisfactory teeming. The ore additions and the oxygen result in the very early formation of a liquid, reactive, limey slag. A cost comparison with the basic-Bessemer process, with and without ore additions, and with the duplex process, shows the economic value of top-blowing with oxygen.—J. P.

**Study of the Mechanical Properties and Cold Working Characteristics of Improved Basic-Bessemer Steel.** R. Langers, H. Herbiet, and F. Montbrun. (*Rev. Tech. Luxembourg*, 1952, **44,** July–Sept., 181–185 ; Oct.–Dec., 240–247). A survey of work carried out using an oxygen-enriched blast, with or without addition of water vapour, and the use of double slags in basic-Bessemer practice, is first given. The results of tests on steels produced by these methods are compared with those carried out on normal basic-Bessemer steel and open-hearth steels. The cold working properties of the improved steels are superior to those produced by the normal basic-Bessemer process, and equal, and at times superior, to those produced by the open-hearth process.—B. G. B.

**Development of Converter Steelmaking : Search for Low-Nitrogen Steels.** (*Iron Coal Trades Rev.*, 1952, **165,** Nov. 21, 1133–1136). The development of steel production in the basic-lined converter is outlined, the various trends being considered from both the economical and technical viewpoints. Particular reference is made to the aim to produce low-nitrogen steel, and the latest techniques to achieve this are described. They include oxygen-enrichment of the blast, the use of mixed blasts which are oxygen-enriched and also diluted with superheated steam or carbon dioxide, and the Suess method where oxygen is injected on to the bath.—G. F.

**Hydrodynamical Study on Scale Models and Full Size on the Nature of Bath Movements in an Iron Converter.** P. Leroy. (*Rev. Mét.*, 1952, **49,** Sept., 673–688 ; Oct., 747–761). Results of tests on scale models using water with and without solid additions are given, and a study of various liquids indicates that the effects of density, viscosity, and surface tension on the critical and limiting wind rates are relatively slight. A systematic study of the influence of geometrical factors on bath oscillation is being carried out. The effects of ' dead zones ' and ' sectors of circulation ' on oscillation are outlined and the problem of size number and location of blowing holes discussed. Permeabilities of a full size convertor, both empty and charged, have been measured. Finally, full-scale trials with a water-filled converter confirm the model results.—A. G.

**Trials to Produce Low Nitrogen Steels in a Small Basic Converter.** K. G. Speith and H. Bücken. (*Arch. Eisenhüttenwesen*, 1952, **23,** Sept.–Oct., 325–333). Although the refining process in an air-blown small converter is essentially the same as in a full-sized unit, less lime can be employed, there is no manganese ' hump ', and cooling with scrap or ore cannot be carried out. The rate of nitrogen pick-up and the final nitrogen content are lower than with a normal converter. With oxygen-enriched blast, it is much easier to make a pourable steel. Blowing times can be as little as one-third of those with air, the lime addition per ton is equal to that in a normal converter, and scrap and ore may be used for cooling. Temperature during both decarburizing and dephosphorizing periods is the most important factor controlling nitrogen pick-up rate. If the temperature is kept as low as possible by judicious additions of cooling agents during the carbon period, and then allowed to rise, it is possible to produce, at a given finishing temperature, a steel with a lower nitrogen content than with air blowing, or for a given nitrogen content, a much hotter metal. The nitrogen pick-up rate is also influenced by the construction of the converter and the method of blowing. The rate can be so low in side-blown and oblique-blown units that blowing time plays only a subsidiary role. The nitrogen partial pressure had no detectable influence in the range of gas compositions of 21–45% oxygen. Refining with $O_2$–$CO_2$ mixtures proceeds normally except that there is a steady reduction in the nitrogen content of the metal down to as little as 0·0013%. Denitriding was never observed with air or enriched-air blowing. Steel from a full-size converter with oxygen-enriched blast contained 0·005–0·007% of nitrogen.

**The Brown Boveri Turbo-Blower in Large Steelworks.** M. Haller. (*Brown Boveri Rev.*, 1952, **39,** May–June, 200–206). The design of turbo-blowers and adaption for steelworks processes are discussed. Special features and methods of control suitable for converter operation are outlined.—T. E. D.

**Vibration Method for Preparing Converter Linings.** A. Latour and J. Schoop. (*Stahl u. Eisen*, 1953, **73,** Jan. 15, 81–84). A new and simple method of preparing tar-dolomite converter bottoms is described. In this, a large number of hollow tubes or ' needles ' are placed in the mixture on the converter base and slowly withdrawn as the mixture is consolidated. A plate, carrying a securely mounted electrical vibrator, and having a series of holes coresponding to the needles, is lowered over these. The action of the vibrator rapidly compacts the tar-dolomite, the needles serving to allow air to escape. The resulting bottom is superior in wear resistance to those prepared by ramming.—J. P.

**Renaissance in Steelmaking Methods.** H. G. Batcheller. (*Steel*, 1952, **131,** Oct. 27, 94–98). The author points out that the increasing size, complexity, and cost of the modern steel-producing plant is encouraging the development of new tech-

niques, particularly of more direct processes. Possible advances in steelmaking are mentioned.—D. L. C. P.

**Automatic Control of Open-Hearth Furnaces : Installations at Works of John Summers & Sons, Limited.** (*Iron Coal Trades Rev.*, 1952, **165,** Dec. 19, 1365 : *Iron Steel*, 1952, **25,** Dec., 539–540 : *Metallurgia*, 1953, **47,** Jan. 25–26). **Shotton's Integrated Iron and Steel Works.** (*Times Rev. Indust.*, 1953, Mar., 14–17). A brief description is given of the comprehensive automatic control scheme installed at the new open-hearth plant of John Summers and Sons Ltd. The instruments are housed in pressurized cubicles.—G. F.

**Rapid Steel Melting in the Open-Hearth Furnace.** V. Mùdry. (*Hutnik* (Prague), 1952, **2,** 12, 260–261). [In Czech]. Methods of flame control, sampling and analysis, removing slag, and adding lime are discussed in relation to melting rate and furnace life.—P. F.

**The Attainment of Maximum Open-Hearth Production.** T. J. McLoughlin. (*Blast Furn. Steel Plant*, 1952, **40,** Dec., 1435–1442 ; *Iron Steel Eng.*, 1952, **25,** Nov., 123–129). The author discusses a number of factors which influence efficient open-hearth practice. Among these factors are the care of furnace hearths and banks, the maintenance of maximum furnace temperature, charging procedure, melting down, hot metal addition, the run-off slag, the lime boil, and wasting heat. Each is discussed in detail, special attention being paid to the time which any one operation takes. The author concludes with an analysis of an ideal heat which has a tap-to-tap time of 8½ hr.—B. G. B.

**Melt Carbon and Related Open Hearth Problems.** W. J. Frisbie, jun. (*Blast Furn. Steel Plant*, 1952, **40,** Aug., 928–932 ; Sept., 1046–1053 ; Oct., 1190–1196 ; Nov. 1325–1330). The author considers a number of factors which influence the efficient operation of open-hearth performance and discusses the quantititave effect that each factor has. The oxidation oxygen, flush-slag oxygen, and melt slag oxygen are first discussed. Examples are given of the calculation of the amount of hot metal to be added from knowledge of the other materials charged, their analysis, and the required specification of the final product. The influence of a number of variables, including melt carbon, on the charge to melt time is considered. The author stresses the advantages to be gained by using basic principles as a guide to open-hearth furnace operation.

**Cooling of the Basic Open-Hearth Furnace.** F. Bartu. (*Radex Rundschau*, 1947, No. 1–2, June, 24–28). Differences in the cooling of acid and basic lined open-hearth furnaces, and advantages and disadvantages of cooling are described. The influence of cooling on fuel consumption and efficiency is discussed, also the costs of cooling. Some general principles of cooler construction and water control are outlined.—E. C.

**Lining of Melting Furnaces and Steel Quality.** F. Rapatz. (*Radex Rundschau*, 1948, No. 1–2, April, 9–14). Ideal properties of furnace linings are stated, and the influence of acid and basic linings on the melt and its inclusions is discussed. The effects of crystalline and glassy low-melting inclusions on the steel properties are considered in detail. It is concluded that basic slags and basic linings give less harmful inclusions than acid ones, and permit better dephosphorization, desulphurization, and deoxidation.—E. C.

**End of Campaign Examination of an Oil-Fired Open-Hearth Furnace Roof.** G. Ziliani and G. Grungo. (*Met. Ital.*, 1952, **44,** Oct., 518–525). The authors examine the different parts of a 35-ton furnace roof at the end of a campaign of 500 heats during which no roof repairs were made. Specimens were submitted to chemical, technical, and microscopical tests. The authors relate the composition of the surface vitrified layers in the bricks to the wear of the bricks. The results obtained indicate that whilst there is a relation between brick composition and wear, this relation is too complex to interpret on the basis of one furnace campaign.—M. D. J. B.

**A New Burner for Tilting Furnaces.** F. Bartu. (*Radex Rundschau*, 1948, No. 5–6, Aug. 123–125). Uses, advantages, and shortcomings of tilting open-hearth furnaces are outlined, showing the advantages to be mainly metallurgical and the disadvantages to be thermo-technical. The latter are due to the burner being fixed and separated from the mobile hearth. A new burner construction introduced by Maerz Ofenbau, G.m.b.H., is described and is claimed to eliminate all shortcomings of other systems. Intensive water cooling is eliminated, reducing cooling losses, and air leakage is prevented.

**The Treatment of Liquid Open-Hearth Steel with Solid Electric Furnace Slag and the Metallurgical Processes during Tapping.** H. Siegel. (*Arch. Eisenhüttenwesen*, 1952, **23,** Nov.–Dec., 417–425). Open-hearth steel was treated with ferrosilicon and solid white carbide slag from an electric furnace, and the slag inclusions in the resulting ingots were determined. The effects of open hearth, electric furnace, and ladle slags on inclusion count (determined on a blue-brittle fractured surface) have been studied. Recommendations are made for control of slag compositions to produce clean steel.—J. P.

**Rapid Basicity Determination for Basic Open-Hearth Slags Using their Mineralogical Constitution.** F. Trojer. (*Radex Rundschau*, 1948, No. 1–2, Apr., 27–37). The mineralogical constitution of basic open-hearth slags is outlined in brief, also the various phase systems and equilibria involved. The narrow limits required for the formation of various constituents permit an accurate assessment of the slag composition by means of microscopic examination of polished and etched slag samples. The method is claimed to be accurate to ± 1% CaO and is described and discussed in great detail.

**Methods of Slag Control in Open-Hearth Process.** S. Tochowicz, L. Andrejev, and P. Polak. (*Hutnik* (Katowice), 1952, **19,** 12, 417–423). [In Polish]. Method of determination of slag basicity by titration with hydrochloric acid of aqueous extracts of open-hearth slags was tested with satisfactory results. On the basis of experimental evidence it is stated that calcium hydroxide in these extracts is derived from the decomposition of tricalcium silicate. The method is recommended for the control of open-hearth slags.—V. G.

**The Control of Slag Constitution as Applied towards the End of the Open-Hearth Process.** I. Petrman. (*Hutnické Listy*, 1952, **7,** 11, 566–575). [In Czech]. A survey is made of the developments in the U.S.S.R. in the use of slags of controlled composition in the basic open-hearth process. Physico-chemical and thermodynamic aspects underlying current practice are discussed—P. F.

**Chemical Behaviour of Sulphur in Iron and in Steelmaking.** J. Chipman. (*Met. Ital.*, 1952, **44,** Oct., 502–511). The bad effects of sulphur in steel are well known and methods for sulphur control have, so far, been based on the addition of an element forming a stable sulphide or, more often, on the use of a very basic slag as a refining agent. The author shows how the laboratory researches of recent years have extended the knowledge of the chemical behaviour of sulphur at high temperatures. (15 references).—M. D. J. B.

**They Are Molding Cinder Pots Bigger and Tougher than Ever.** (*Amer. Foundryman*, 1952, **22,** Oct., 53–55). Larger cinder pots are now needed for carrying molten slag, because of the increasing use of low-grade iron ore, the use of oxygen which makes the slag frothy, and because transport is more nearly proportional to the number of trucks than to the slag weight. Consequently some cinder pots exceed 500 cu. ft. in volume. Design has been improved by corrugating the wall, and by better placed supporting lugs. The manufacture of these pots is illustrated.—E. T. L.

**The Oxygen-Carbon Equilibrium in Steel.** Rocquet. (Commission d'Ingénieurs : *Centre Doc. Sidér. Circ. Inform. Tech.*, 1951, No. 11, 1265–1279). Work performed by Lacomble and Nepper is reported. Evidence derived from a large number of oxygen determinations on the contents of a basic open-hearth furnace indicates that the oxygen content of the steel depends chiefly on the carbon content and only to a small extent on the FeO content of the slag. This is true at least in the region of basicity generally existing in a basic open-hearth furnace. The results are compared and discussed with work of other authors along similar lines. The experimental methods employed are described and discussed. The oxygen was determined by immersing, in the bath of the furnace, a steel bomb filled with aluminium powder. After immersion for a suitable length of time, the alumina formed was determined by the Swinden nephelometric method. This rapid method, which is described, is empirical and must be standardized.—T. E. D.

**On the New Treatment of the Reaction between Gas Mixture $H_2O$–$H_2$ and Molten Iron in Steelmaking.** T. Yagihashi. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1951, **4A,** Apr., 139–149). [In English]. Takeuchi's statistical thermodynamical theory of the basic reaction in steelmaking was compared with experiments on the equilibrium relation between molten iron and

the gas mixture $H_2O$–$H_2$. The potential energies between atom pairs of Fe–O and Fe–H, and the characteristic vibration temperatures of atomic oxygen and hydrogen in molten iron were determined therefrom.—J. G. W.

**Statistico-Thermodynamical Studies on Fundamental Reactions Concerning Steelmaking. II.—Oxidation and Reduction Equilibrium of Wüstite FeO with Gas Phases.** S. Takeuchi and K. Igaki. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1951, **4A**, Apr., 164–175). [In English]. On the assumption that wüstitè is an ionic crystal containing vacant lattice points formed by the removal of $Fe^{++}$ and the accompanying electron deficits in the form of $Fe^{+++}$ distributed among the $Fe^{++}$ lattice points, the partition function and free energy of such a crystal were calculated. The derived formula for the equilibrium relation between the gas phase and wüstite is in good agreement with quoted experimental results.

**The All-Basic Open-Hearth Furnace in the Steelmaking Industry.** D. W. Duley. (*J. Birmghm. Met. Soc.*, 1952, **32**, Sept., 90–102). The problems associated with all-basic open-hearth furnaces are briefly outlined, and the author discusses the construction of regenerators, slag pockets, uptakes, hearths, and roofs. The stresses involved in roof construction are dealt with, and finally automatic control and the advantages of such furnaces are considered.—P. M. C.

**Increasing Steel Output: Discussions to Implement Productivity Report.** (*Iron Coal Trades Rev.*, 1952, **165**, Oct. 17, 847–851). A summary is given of the proceedings of a B.I.S.R.A. Conference arranged to discuss the conclusions and recommendations contained in the report of the Iron and Steel Productivity Team which visited America, and to consider the possible application of certain American methods to British industry. The aspects considered include size and layout of shops and furnaces, metallurgical load, charging rates, fuel consumption, refractories, and furnace availability.

**Treatment of Iron Between the Blast-Furnace and Open-hearth Furnace: Techniques Used at Scunthorpe (Lincs).** P. E. Colinese. (*Iron Coal Trades Rev.*, 1952, **165**, Oct. 10, 813–816). A summary is given of research trials carried out at the Appleby-Frodingham Steel Co. on methods of treating blast-furnace iron before charging into the open-hearth furnace. Various ladle and mixer treatments are outlined, and the economics of the methods and their effect on steel outputs are examined.—G. F.

**Application of Russian Experiences and Methods in the Metal Industry.** D. Lysenko. (*Hutnické Listy*, 1952, **7**, 11, 563–566). [In Czech]. Czechoslovakian steelmaking methods are critically examined and reference is made to the time wasted in reducing the carbon content of an open-hearth furnace charge to about 0·08% and then making the carbon content up with anthracite additions, instead of tapping when the required carbon content is reached during the refining stage.—P. F.

**Sale of Uranium Contaminated Steel Scrap Recommended.** H. Blatz. (*Iron Age*, 1952, **170**, Sept. 25, 125–127). The American Atomic Energy Commission has recommended the release of uranium contaminated scrap through commercial channels. A study has shown that there is no health hazard in handling this scrap or products from it. Previously, all scrap was shipped to a central point for special processing.

**Advancements in the Construction of Electric Arc Furnaces.** L. Hütter. (*Radex Rundschau*, 1948, No. 1–2, Apr., 15–26). Developments in American and European construction and practice are compared and discussed, and furnace life is studied. Roof construction is dealt with in detail.—E. C.

**Electric Furnace Department Manufactures Large Ingots for Specialized Forge Plant.** A. H. Allen. (*Metal Progress*, 1952, **62**, Oct., 118–120, 196, 198). A description is given of a new electric melting shop containing two top-charging electric melting furnaces of 30 tons capacity. The new melting shop avoids the necessity of reheating the ingots, and this results in the firm having a close control over the ingot composition.

**Philippine Plant Makes First Steel.** (*Steel*, 1952, **131**, Aug. 18, 108–111). A new steel plant operated by the Marcelo Steel Corp. in Manila has started production. The equipment consists of three electric-arc furnaces, a cogging mill, and a re-rolling train. At present reinforcing rods $\frac{3}{8}$ to 1 in. in dia. are being produced.—A. M. F.

**Continuous Casting Machine Will Soon be in Operation at Welland.** (*Blast Furn. Steel Plant*, 1952, **40**, Dec., 1456, 1468). **Atlas to Continuously Cast Steel Billets, Slabs.** (*Canad. Metals*, 1952, **15**, Dec., 18–19). A short description of a continuous casting machine for use with tool, stainless, and other high-grade steels which is to be erected at Welland, Canada, is given.—B. G. B.

**Ingot Mold Wash Ends Coating Fumes.** G. P. Michalos and D. J. Girardi. (*Steel*, 1952, **131**, Dec. 8, 106–111). Syncoat, the mould wash described, has the good qualities of tar and pitch, but does not give off the heavy fumes normally present during coating and pouring.—D. L. C. P.

## FOUNDRY PRACTICE

**Advancements in Founding in the First Half of 1952.** P. A. Heller. (*Stahl u. Eisen*, 1953, **73**, Feb. 12, 230–234; Feb. 26, 296–299). The literature is reviewed. (104 references).—R. A. R.

**Present Developments and Future Trends in the Cast Iron Industry.** J. McGrandle. (Inst. British Foundrymen: *Foundry Trade J.*, 1953, **94**, Jan. 29, 125–129). In a broad survey of the ironfounding industry the present developments and trends are indicated and the interdependence of all factors involved in the industry are stressed. The forces governing present tendencies are discussed and an attempt is made to indicate how far these developments may affect the industry.—L. E. W.

**The Cupola Process in the U.S.S.R.** Z. Tyszko. (*Przeglad Odlewnictwa*, 1952, **2**, 10, 317–321). [In Polish]. An outline of the development of cupola design and operation in the U.S.S.R. is given.—V. G.

**The Effect of Raw Materials on Cupola Operation.** B. P. Mulcahy. (*Foundry*, 1952, **80**, Mar., 144–148, 153; May, 242–244; June, 284–286; July, 211–216; Aug., 146–153; Oct., 206–211; 1953, **81**, Jan., 158, 160). The author discusses the effects of pig iron, scrap, fuel and fluxing, and deals with the effect of the quantity and composition of the pig iron, distinguishing between the effects of size of scrap, oxidation and burning, aluminium, and borings. It is suggested that sorting of scrap is useful and economic, and mention is made of the precautions to observe in the use of steel scrap and foundry returns.—E. T. L.

**Notes on Cupola Operation.** A. G. Gardiner. (*Foundry Trade J.*, 1952, **93**, Oct. 16, 457–458). It is suggested that cupolas should be charged uniformly with scrap not larger than one-third the cupola diameter, and to a height sufficient to use the heat in the gases. Cupolas should be used on alternate days to allow regular repairs.—E. T. L.

**Cupola Deoxidation Improves Iron Casting Machinability.** F. S. Kleeman. (*Amer. Foundryman*, 1952, **22**, Oct. 61–66). The machining of iron castings often costs more than the castings themselves. Machinability can be improved by a melting deoxidation process using briquettes of silicon carbide for deoxidizing the iron in the cupola. This method reduces the iron oxide content of the slag also. The improvement of machinability has been shown by tests, and is explained by the greater dispersion of carbides, graphite and steadite, which follows from the cupola deoxidation.—E. T. L.

**Means for and Methods of Economising on Furnace Coke.** H. Sommer. (*Technik*, 1952, **7**, Aug., 449–454). The author exhorts workers in foundries and gasworks to use gas coke in place of furnace coke. Factors influencing quality of gas coke, methods of reducing the consumption of furnace coke in cupolas, and the use of fluorspar and peat coke, are described.

**Water-Cooled Cupolas.** N. A. Barinov, V. P. Mizikin and E. M. Blank. (*Przeglad Odlewnictwa*, 1952, **2**, 11, 359–360). [In Polish, translated from *Liteinoe Proizvodstvo*, 1951, No. 12]. The design of water-cooling equipment for cupolas and some operating data from these cupolas are given. The advantages claimed are: (1) Reduction in the thickness of the lining, thus increasing the volume of the cupola; (2) a higher melting rate; (3) a higher tapping temperature; and (4) longer lining life.—V. G.

**Recent Developments in Cast Iron Metallurgy.** A. B. Everest. (*Metallurgia*, 1952, **46**, Dec., 293–297). Some of the more important developments applied to cast iron and its foundry practice are reviewed. The production and application of castings with graphite in the spheroidal form, and developments in melting and moulding practice are discussed in detail.—B. G. B.

**Automatic Air-Weight Control of Cupola Blast.** P. Glass. (*Indust. Heating*, 1952, **19**, Oct., 1842–1846). The Askania automatic air-weight control is described. Power consumed by the blower motor is a measure of the weight of air delivered and furnishes a signal to actuate the hydraulic control system.

The measuring system is a wattmeter designed to measure the power input to the blower motor and to produce a mechanical torque proportional to it.—B. G. B.

**Electric Resistance Furnace for Melting Metals.** S. Kaczorowski. (*Przeglad Odlewnictwa*, 1952, **2**, 11, 341–346). [In Polish]. The design of a 300-kg. carbon-rod-resistor tilting furnace, and its electrical and mechanical equipment are described.—R. A. R.

**High Silicon Acid-Resisting Iron.** R. V. Riley. (*Modern Foundry*, 1952, No. 2, 1–15). The author discusses briefly the excellent acid-corrosion resistance of the 14·5%-silicon iron alloys, with a critical carbon content in the range 0·50–0·65%. Such alloys are used extensively in the chemical industry, and have a Brinell hardness of about 450 and a tensile strength of about 10 tons/sq. in. Brief details are given of the pattern, mould, and core requirements when designing and producing castings.—P. M. C.

**The Addition of Tellurium to Cast Iron.** D. Magri. (*Fonderia Ital.*, 1952, **1**, Oct., 171–172). After briefly describing the properties of tellurium, the author shows how it can be used in small quantities with cast iron as an energetic carburizing agent. It is suggested that tellurium may, with advantage, replace the present practice of adding ferrochromium which has the disadvantage of lowering the temperature of the cast. It is claimed that, by using tellurium, iron castings of very different sizes can be made from one heat. Tests show that the addition of tellurium improves temper and Brinell hardness, but lowers slightly the tensile and bending strength.—M. D. J. B.

**Spheroidal Graphite Iron Featured At International Nickel Open House.** (*Amer. Foundryman*, 1952, **22**, Oct., 83). Iron is inoculated in two stages, in this process. In the first 'nodulizing' step, the cupola is tapped directly on to the nickel–magnesium alloy resting on the bottom of the receiving ladle. In the second, the 'graphitizing' step is carried out by adding ferrosilicon while the metal is poured into the pouring ladle. Examples are given of the improvement in properties, and of typical uses for this type of iron.—E. T. L.

**Some Effects of Magnesium on the Formation of Graphite in a Solidifying Cast Iron.** I. C. Hughes. (*Foundry Trade J.*, 1952, **93**, Sept. 25, 349–356 ; Oct. 2, 385–391 ; Oct. 9, 417–423). Illustrations show the progress of solidification of inoculated iron with and without magnesium. The author concludes that magnesium depresses the eutectic temperature, spheroidizes the graphite particles, and increases the tendency of the eutectic liquid to solidify as iron–carbide eutectic.

**Influence of Phosphorus Present in Irons Containing Spheroidal Carbon.** M. Grandpierre and H. de Bouvier. (*Rev. Mét.*, 1952, **49**, Oct., 689–698). Pure Armco irons with varying amounts of phosphorus were inoculated with a magnesium–iron–silicon alloy followed by ferrosilicon, and examined microscopically and mechanically. Phosphorus makes cast parts more brittle and above 1% fissures appear, but it does not prevent spheroidal graphitization.—A. G.

**The Mechanism of Nodular Graphite Formation in Cast Iron.** I. Aoki. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1952, **4**, June, 273–282). [In English]. When Cu–Mg alloy is added to molten iron, some magnesium volatilizes and some enters into solution. A remaining portion of the Cu–Mg is not dissolved, and disperses as small particles. On adding silicon, carbon separates on the boundaries of these particles. If the particles are small, the graphite covers them, becoming spherical ; on large particles the graphite grows towards the interior and is spheroidized by being covered with the Cu–Mg alloy. A similar mechanism is postulated for Ni–Mg or pure magnesium treatment.—K. E. J.

**Some Studies of Nodular Graphite Cast Iron.** M. Isobe and A. Chida. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1951, **3**, June, 297–307). [In English]. A study of graphitization was made on white pig iron using several different magnesium alloys. Use of multi-component alloys enabled a fully ferritic matrix to be obtained. Retention of magnesium was better when small amounts were added. Hardness of cast iron decreases with annealing, and with increase of diameter of casting. The decomposition of pearlite in nodular iron is comparatively rapid. A modification to Myskowsky's structural diagram is proposed.—K. E. J.

**On the Spheroidization of Graphite and Its Disintegration in Magnesium-Treated Irons.** M. Okamoto and R. Yoda. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, June, 347–351). [In Japanese]. Changes were investigated in molten irons held at 1350–1400° C., after treatment at 1400° C. with 0·9% Mg (from a Mg–Si–Cu–Fe–Al alloy). Chemical changes accompanying spheroidization, its disintegration, and later decarburization are described. Spheroidization effects decreased when chlorides, fluorides or oxides were added.—K. E. J.

**Study on the Pig Iron Used in the Production of Nodular Cast Iron. III.—Effect of Gases in the Pig Iron on the Graphite Nodulization.** T. Tanaka, T. Ishiwatari, and R. Sagawa. (*J. Mech. Lab.*, 1952, **6**, Sept., 196–200). [In Japanese]. Magnesium-treated iron showed reduced gas content, and pronounced deoxidation. Oxidation of irons, when molten, caused imperfect nodules because of oxidation of the magnesium added.—J. G. W.

**Effect of Oxidation Rates on Graphitization of Cupola Melted Malleable.** M. Tilley. (*Amer. Foundryman*, 1952, **22**, Oct., 46–47 ; *Foundry*, 1952, **80**, Nov., 108–109, 160). The number of carbon nodules in unit volume of holding furnace iron is inversely proportional to the rate of loss of silicon. Hence the oxidation rate is deduced to control the graphitization rate, by a mechanism still obscure.—E. T. L.

**Research on the Relation of Cast Iron and Oxygen. On the Mechanism of White Cast [Iron Formation] by Carbide-Forming Metallic Elements.** M. Homma and Y. Hashimoto. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, Mar., 169–173). [In Japanese]. Carbide-forming metallic elements behave in an analogous way to oxygen in promoting white cast iron formation, although the amounts needed differ greatly. This behaviour is explained by the similarity of clusters of the type Fe–O–C–Fe and Fe–M–C. (13 references).—K. E. J.

**Soviet Achievements in the Production of Malleable Cast Iron.** J. Piaskowski. (*Przeglad Odlewnictwa*, 1952, **2**, 10, 311–317). [In Polish]. A survey is made of Russian literature on malleable cast iron. (22 references).—V. G.

**Carbon and Low Alloy Steel Castings.** P. O'Keefe. (*Mat. Methods*, 1952, **36**, Sept., 119–134). This comprehensive review is intended to give the materials engineer the information he needs to consult intelligently with the foundry on design problems and applications.—P. M. C.

**Some Recent Developments in Foundry Sand.** N. L. Bush. (*Australian Found. Trade J.*, 1952, **4**, Sept., 3–13). The article deals mainly with clays and the desirable characteristics for bonding. The structures of various American, Australian, and British clays are discussed and their relative merits for foundry use are considered.—P. M. C.

**The Sand in Your Foundry.** (*Modern Foundry*, 1952, No. 3, 6, 7). Brief details are given of sand control and testing equipment for the determination of moisture, fineness, permeability, and mould and core hardness.—P. M. C.

**Foundry Sand Control.** A. Tipper. (Inst. British Foundrymen : *Foundry Trade J.*, 1953, **94**, Jan. 22, 99–101). Those characteristics of moulding sands are discussed which are of particular importance to foundrymen in producing good moulds and good castings. Methods at present used for routine sand control, the investigation of sand properties, and possible causes and cures for certain sand troubles are reviewed.

**The Problem of Standardizing the Testing of Foundry Sands.** G. Ziliani. (*Fonderia Ital.*, 1952, **1**, Nov., 197–204). After reviewing the methods of testing foundry sands adopted in different countries, the author describes in greater detail the methods put forward by Sirovich, Prever and Balina after which the methods suggested by the Italian, German, and American specifications are critically examined. (26 references.)—M. D. J. B.

**Properties and Preparation of Synthetic Sands.** V. Niola. (*Fonderia Ital.*, 1952, **1**, Oct., 173–176). The author examines the uses of synthetic sands in Italy and describes such factors as expansion, the resistance to heat, distribution and shape of grain size. Both sands and clays are considered and chemical and mechanical properties are discussed.—M. D. J. B.

**Sequence of Adding Ingredients to a Core Mix.** (*Modern Foundry*, 1952, No. 3, 1, 2, 4). Brief details are given of tests carried out to determine whether the sequence of adding ingredients to a core mix had any effect on the resultant mix. The mix studied was made up of 25 lb. of lake sand, 113·5 g. of cereal binder, 113·5 g. of 'Linoil', and 300 c.c. water. All seven possible addition orders were tested, and the best core properties were obtained by the sequence cereal–water–oil.

**Chemically Hardened Foundry Sands.** L. Petržela. (*Hutnické Listy*, 1952, **7**, 11, 575–585). [In Czech]. This is a detailed discussion of the use of water-glass additions to foundry sands, and their practical applications.—P. F.

**How The One-To-Ten Ram Test Measures Sand and Mold Properties.** C. A. Sanders and A. G. Clem. (*Amer. Foundryman*, 1952, **22,** Oct., 48–50). The authors believe that mould hardness, green compression strength, permeability, and density can only be considered usefully together. These factors are correlated with degree of compression in a ramming test, giving results which may be usefully connected with practical moulding operations. Typical curves of these four factors against compression are given, for desirable and undesirable types of sand.—E. T. L.

**Surface Finishing and Facing Sands.** R. Pell. (Inst. British Foundrymen : *Foundry Trade J.*, 1953, **94,** Jan. 1, 5–11). The author describes experiments on sand practice at Hayward-Tyler's foundry. It is possible to make a 16-cwt. casting in green sand. The surface quality was improved by using suitable coal dust in the synthetic sand, and by the addition of wood flour.—E. T. L.

**Sand Treatment.** A. S. Beech. (*Canad. Metals*, 1952, **15,** Feb., 28–31). The author condemns the batch sand mill fitted with the stationary pan and revolving mullers. In its place is recommended a continuous mill, adaptable to batch treatments on certain occasions, but using a revolving pan as well as revolving mullers. In the latter, the special silica sand particles are rubbed, not ground, especially if the mullers are long and do not rest on the bottom of the pan. By manipulating the ' diverters ' the mill may be made to deliver sand which has been intensively milled.—J. C. B.

**The Influence of Iron Compounds on the Sintering of Moulding Sands.** T. R. Gamsachhurdia and K. S. Kutateladze. (*Przeglad Odlewnictwa*, 1952, No. 5, 162–164). [In Polish]. The influence of magnetite, hematite, limonite, and pyrite on the sintering of moulding sand was investigated on a laboratory and industrial scale. It is concluded that the maximum amount of iron compounds allowed in a moulding sand must be included in the standards for moulding sands.—V. C.

**Production of Sound Castings.** H. W. Griffiths. (Inst. Brit. Foundrymen : *Foundry Trade J.*, 1952, **93,** Aug. 7, 153–156). Examples are described of the successful use of certain runner systems, chills, pressure feeding, and thermit to produce sound iron castings. The preparation of moulds for casting solid iron spheres 6 in. in dia. is also discussed.

**Synthetic Resins for Foundry Use.** (*Engineer*, 1952, **194,** July 18, 85–86: *Engineering*, 1952, **174,** July, 87–88). An account is given of the properties of cores bonded with synthetic resins and their use in other moulding processes. The materials and techniques described are those now under investigation and development at Imperial Chemical Industries Ltd., Plastics Division, Welwyn.—M. D. J. B.

**Effect of Blacking Additions to Core and Molding Sands.** T. H. Burke. (*Foundry*, 1952, **80,** July, 110–111, 234–235). The author describes the successful use of a relatively cheap mixture of sands and blacking which is suitable for complicated castings in which the core is surrounded by large masses of metal.—E. T. L.

**Comparison Between Bentonites and Their Uses in Foundries.** A. Catelani and G. Somigli. (*Fonderia Ital.*, 1952, **1,** July, 36–38). The authors suggest that the practical properties of bentonites used as synthetic or agglomerated moulding sands do not always bear relation to their physico-chemical characteristics as determined in the laboratory. Twelve natural bentonites are examined and submitted to cold and hot tests.—M. D. J. B.

**New Experiences with Moulding in Cement Sand.** M. Beilhack. (*Giesserei*, 1952, **39,** Aug. 21, 405–410). In the first part of the paper laboratory investigations on Portland cement and iron Portland cement sands are reported. Although the latter is somewhat inferior, its compressive strength is thought to be sufficient for mould and cores. In the second part, industrial experiences with synthetic sands are discussed.—J. G. W.

**An Exothermic Feeding Compound : Its Use with Steel Castings.** E. Lazendorfer. (*Iron Steel*, 1952, **25,** June, 283–288). The author describes the use of the exothermic feeding compound ' Feedex ' in the riser heads of steel castings. The material, which is mouldable to any desired shape, also acts as an insulator after burning out ; this combined action results in the feeding metal remaining liquid three or four hours longer than usual and enables the risers to be reduced to one-third or one-quarter of the normal size.—G. F.

**Practical Application of Sand and Mold Handling Equipment.** H. W. Zimnawoda. (*Foundry*, 1952, **80,** Apr., 88–93, 197, 200–201 ; May, 162–167). The author reviews the layout of equipment, and indicates the best means of material transport, handling methods at the shakeout, and sand reclamation.—E. T. L.

**Foolproof Sand Works for Wide Range of Castings.** J. S. Schumacher. (*Amer. Foundyman*, 1952, **21,** June, 54–57). The author recommends a mixture of 60% lake sand with 40% bank sand, to give a mixture with a wide range of grain size. This wide range is believed to account for an improvement in the quality of the castings.—E. T. L.

**Cement-Bonded Molding Sand.** C. D. Galloway. (*Amer. Foundryman*, 1952, **21,** May, 67–69). Cement-bonded moulding sand allows close tolerances and better surface finish, and is more economical for large jobbing castings. The low green strength necessitates the frequent use of rammed cores, and prevents its use on small castings. The technique of cement moulding is briefly described.—E. T. L.

**Use of Synthetic Sands Including Cement Sands.** E. Lange. (*Giesserei*, 1952, **39,** Aug. 7, 387–390). The use of synthetic sands in steel casting is discussed. Attention is drawn to the need for the correct choice of binder and grain size in sands for green sand casting.—J. G. W.

**Synthetic Moulding Sand—The Method and Advantages of Using It in Grey Iron and Steel Foundries.** H. Gries and W. Trommer. (*Giesserei*, 1952, **39,** July 10, 333–341). Bentonite sands are described, their properties defined, particulars of tests given, and the economic aspects of their use considered.—J. G. W.

**Easier, Surer Identification with Colored Core Sands.** L. C. Voss and W. W. Lynn. (*Amer. Foundryman*, 1952, **22,** July, 44–45). Small additions of organic dyestuffs to different grades of core sand show undermixing, prevent wrong distribution, indicate faulty core structure, and point to uncured cores. The authors explain how to add and use the dye.—E. T. L.

**For Accurate Green Sand Test Results Standardize, Maintain Testing Equipment.** (*Amer. Foundryman*, 1952, **22,** Aug., 53–55). This is a series of recommendations for the best use of equipment for measuring weight, moisture, ramming, permeability, and green strength of moulding sand.—E. T. L.

**Working with Synthetic Moulding Sand.** K. Houben. (*Giesserei*, 1952, **39,** July 10, 341–343). The practical advantages of bentonite moulding sands are briefly surveyed.

**Characteristics of Foundry Moulding Sands.** M. N. Khanna and B. R. Nijhawan. (*Metal Market Review*, 1952, **5,** June 16, 11–15; June 23, 11–14; June 30, 9–14). After briefly reviewing the types of sand and the use to which they are put in the foundry, the authors discuss the effects that variations in he properties of the moulding sands have on the suitability of the material for foundry use. Some simple sand-testing procedures are described.—B. G. B.

**Structure and Properties of Natural and Synthetic Foundry Sands.** R. Grochalski. (*Met. u. Giessereitechn.*, 1952, **2,** Feb., 34–37; Mar., 76–82). This paper deals with the nature and structure of the constituents of moulding sands; and the composition, grain size distribution, and grain shape of sands from various sources; the effect of water content and grain size on the compressive strength and permeability of moulding sand mixtures; the surface activity of natural sands and the chemical and mineralogical nature of the constituents binding the grains together; X-ray diffraction patterns of binding materials; and the activating of quartz sands.—H. R. M.

**Properties and Testing of Moulding Sands.** J. Vazquez White. (*Anales de Mec. y. Elec.*, 1952, **29,** Jan.–Feb., 25–32). [In Spanish]. The author reviews briefly the properties required in moulding sand and describes the usual laboratory tests for determining sand quality.—R. S.

**Synthetic Foundry Sands. Study of a Synthetic Foundry Sand for Casting Test Bars in High-Strength Cast Iron.** A. T. de Sousa Carvalho. (*Bol. do Inst. Nac. de Tecnolog.*, 1951, **2,** Sept., 14–38). [In Portuguese]. Detailed tests were carried out on silica sands of the Federal District (Brazil) with the object of producing a sand to satisfy the American Foundrymen's Assoc. specifications.—R. S.

**Influence of Different Clay Binders on the Properties of Moulding Sands.** O. Carlsson and S. Rydén. (*Gjuteriet*, 1952, **42,** Oct., 157–165). [In Swedish]. Tests showed that African calcium bentonite and American sodium bentonite gave almost the same green strength, although the latter has an increased cracking tendency and greater dry strength. Kaolinite causes less surface brittleness than bentonite. Variation of surface

brittleness in different sands is due to varying migration velocity of water. Sodium bentonite gives greater hot strength than calcium bentonite or other clays, with the result that less scabbing occurs and mould life is longer. Kaolinite moulding sands have the shortest life.—G. G. K.

**Chemically Hardened Foundry Sands.** L. Petržela. (*Hutnické Listy*, 1952, **7**, 10, 514–517). [In Czech]. Results of research on the use of waterglass additions to foundry sand mixtures are reported.—P. F.

**The Application of Lignite Ash as a Moulding Material.** R. Grochalski. (*Met. u. Giesserei Techn.*, 1952, **2**, Apr., 101–108).

**Measurement of the Gas Content of Cores.** F. Roll. (*Giesserei*, 1952, **39**, Nov. 13, 603–606). Four methods of measuring the quantity of gases released by cores during casting are described and their advantages and drawbacks are discussed.

**The Behaviour of Cores During Casting.** P. Nicolas. (*Fonderie*, 1952, Aug., 3043–3059). The penetration of metal into cores, knocking-out difficulties, casting defects due to core gases, and the effects of different quality and quantity of core binders are discussed. Means of limiting the evolution of core gases are also considered.—R. S.

**The Nature of High Pressure Risers.** J. Přibyl. (*Hutnické Listy*, 1952, **7**, 10, 523–528). [In Czech]. The use of high pressure on castings by introducing gas-generating charges into the riser is discussed, and a brief survey of the principles involved is given. Questions relating to the best position of the $CaCO_3$ charge in the riser, the temperature and pressure of the gases in the high-pressure cavity formed, the influence of high-pressure risers on microshrinkage, structure of the castings, and the ratio of metal poured to metal in the finished casting are discussed.—P. F.

**The Williams' Riser and the Quality of Steel Castings.** R. Kloda and J. Zábrš. (*Hutník*, (Prague), 1952, **2**, 11, 236–240). [In Czech]. Several examples are described and illustrated to show the correct method of positioning risers on steel castings. X-ray photographs show the improvements in quality which can be obtained.—P. F.

**Design Aspects of Pneumatic Moulding Machines.** J. Broberg and L. Villner. (*Gjuteriet*, 1952, **42**, Nov., 175–191). [In Swedish]. Recommendations made by the moulding machine committee of the Swedish Federation of Machine Manufacturers are intended to aid manufacturers to satisfy the practical needs of foundrymen. Another section of the report discusses design of some moulding machine parts in detail and suggests improvements.—G. G. K.

**Foundry Mould and Core Washes.** C. Dias Brosch. (*Bol. da Assoc. Brasil. Metais.*, 1952, **8**, July, 225—233). [In Portuguese]. The main types of foundry mould and core washes and their uses are described.—R. S.

**Experimental Study of the Efficiency of Recirculation in a Foundry Stove.** G. Ulmer. (*Fonderie*, 1952, May, 2917–2926; June, 2971–2982). To study the effectiveness of recirculation stoves in mould drying, a test stove was used on a production scale, with and without circulation. This stove is described and the advantages of recirculation are discussed.—R. S.

**The Production of Some Iron Castings for the Iron and Steel Industry in Semi-Permanent Sand Moulds.** S. Kwiatkowski. (*Przeglad Odlewnictwa*, 1952, **2**, 9, 300–301). [In Polish]. The preparation of semi-permanent sand moulds for ingot-mould trumpets and ladle segments is described. Up to 100 castings can be made with only small repairs after each casting.—V. G.

**Snap Flask Moulding.** M. Sarnecki. (*Przeglad Odlewnictwa*, 1952, **2**, 9, 277–283). [In Polish]. The equipment and methods of operating the snap flask moulding process, and its advantages, are discussed.—V. G.

**Precision Casting by the Lost Wax Process—Its Application to the Casting of Small Parts in Steel and Heat-Resisting Alloys.** E. Morlet. (*Métaux-Corrosion-Indust.*, 1952, **27**, Oct., 401–413). A detailed description of the various stages in the manufacture of turbine blades and similar parts by the lost-wax process is given. Depending on the conditions of service of the parts, many different types of alloy steel are used. Among these are 13% Cr, 18/8 stainless type (stabilized with titanium or quenched from 1100° C.), 20–25% Cr and 15–20% Ni, 30–35% Ni and 12–15% Cr, and austenitic steels with tungsten. Alloys containing large amounts of manganese are not suitable owing to attack of the mould wall.—B. J. B.

**"Inversion Casting" of Cylindrical Milling Cutters.** O. Morávek and V. Baborovský. (*Hutnické Listy*, 1952, **7**, 10, 528–531). [In Czech]. The quality of forged and cast high-speed steel tools, and the economic advantages of casting, particularly by the "furnace inversion" method, are considered. In this process the mould is directly attached to the electric furnace in which the metal is melted in a reducing atmosphere so that no slag is formed. On inverting the furnace the metal runs into the mould. There are no heavy feeders, and oxidation is prevented. Ordinary oil-bound foundry sands can be used. The surface of the castings is somewhat coarser than in conventional practice, but this is of no consequence as the milling cutters have to be finished and ground in any case.—P. F.

**The Manufacture of Cast Edge Tools in Rotary Furnace Steel.** G. Keech. (*Australian Found. Trade J.*, 1952, **3**, Aug., 3–5, 7–9). Keech Castings Pty. Ltd., N.S.W., are producing axes, hatchets, hammers, and shears, in a silicon–manganese steel by direct casting into moulds made in pitch-bound core sand. Cutting edges are locally hardened to C 58–60 Rockwell, and excellent service is obtained. Such products are much cheaper than similar forged articles. The process is described.—P. M. C.

**New Casting Resin Used for Low Cost Forming Tools.** J. Starr. (*Mat. Methods*, 1952, **35**, May, 105–107). Long lasting, accurate jigs and dies are rapidly and easily produced with a new phenolic resin which has low viscosity and does not retain air bubbles as it solidifies. Its properties are tabulated and types of mould are discussed.—P. M. C.

**Precision Investment Castings: Cleaning in Molten Caustic Soda.** N. L. Evans. (*Iron Steel*, 1952, **25**, Sept., 396–397). In the production of precision investment castings, a problem encountered is the complete removal of the investment material from the metal. The author describes a process in which the castings are desanded by immersion in molten caustic soda at 500–530° C., and then descaled in a second bath of caustic soda at 350–370° C. which contains a small proportion of sodium hydride. This reduces the scale without attacking the underlying metal. The method is applicable to most metals and alloys.—G. F.

**Materials and Equipment for Shell Mouldings.** (*Machinery*, 1952, **80**, June 19, 1077–1078). The use of 'Thur' shell-moulding resin is described.—R. A. R.

**Shell Moulded Stainless Valves and Fittings now in Production.** G. F. Sullivan. (*Iron Age*, 1952, **169**, June 26, 112–116). A description of the shell moulding of valves and fittings in types 304 and 316 stainless steel is given. Standard green sand cores with resin-bonded sand shell moulds are used. Good tolerance, smooth finish, and no cleaning problems are some of the advantages. The finished moulds take up little room and can be stored indefinitely.—A. M. F.

**Current Status of Shell Molding.** R. Herold. (*Amer. Foundryman*, 1952, **22**, Aug., 42–46; *Iron Steel*, 1952, **25**, Dec., 533–534). Precision casting, at costs similar to those of normal sand casting, by shell moulding is finding increased application. It extends the employment of unskilled nad female labour. Accuracies of $\pm$ 0·002 in. are claimed.

**British Firm Goes Ahead with Shell Moulding Process.** J. Fallows. (*Machinist*, 1952, **96**, Nov. 29, 1927–1931). Shell moulding was first introduced by Croning in Germany. Striking claims are made for the process. This article is the first detailed description based on British practice.—E. C. S.

**The Shell Moulding Process—Methods Employed by Polygram Casting Co., Ltd., Chiswick.** (*Machinery*, 1952, **81**, Nov. 28, 1111–1116; *Light Metals*, 1952, **15**, Aug., 268–269). **Shell Moulding.** (*Brit. Eng.*, 1953, **35**, Feb. 283–284; *Iron and Steel*, 1953, **26**, Feb., 67–68; *Machine Shop Mag.*, 1952, **13**, Dec., 561–566).

**Cement-Sand Moulding: Layout and Practice at the David Brown Foundries Company.** (*Iron Steel*, 1952, **25**, Oct., 441–446). A detailed description is given of the layout and sequence of operations at the David Brown Foundries Co., Penistone, where the Randupson process of cement-sand moulding is employed.—G. F.

**In the Steel Foundry—15.** (*B.S.F.A. Log.*, 1952, Oct., 4–7, 14–16). This is a review of the development of Carntyne Steel Castings Co., Ltd. until North British Locomotive Co., Ltd. bought the entire shareholding. In the foundry, Belgian sand is used, thereby eliminating the necessity of using large quantities of bentonite. The steel is supplied from two cupolas feeding two Tropenas converters. Details of moulding, core making, and heat-treatment of the castings are given.

**Development of Steel Foundries in India.** N. G. Chakarbarti. (*Metal Market Review*, 1952, **5**, Aug. 25, 19–22; Sept. 1, 10–14, 9). A detailed examination of past and present Indian foundry practice is made.—B. G. B.

**Some Examples of Moulding Floors Where Moulds are Handled by Roller Conveyor.** (*Fonderie*, 1952, Aug., 3065–3070). Six examples of moulding floors employing roller conveyors are illustrated and described.—R. S.

**Modernization and Mechanization of Foundries.** D. Iturrioz. (*Met. y Elec.*, 1952, **16**, May, 32–36; June, 62–68; July 29–32; Aug., 31–34; Sept., 37–41). [In Spanish]. This series of articles reviews current foundry practice with moulding machines, core-moulding, stripping, shake-out machines, and surface-finishing operations.—R. S.

**The Mechanization of Transport in Foundries.** H. Sioda. (*Przeglad Odlewnictwa*, 1952, **2**, 9, 289–295). [In Polish]. The advantages of mechanization in foundries and some typical conveyor systems are discussed.—V. G.

**How Variations in Water Affect the Properties of Bentonite.** F. L. Cuthbert and T. M. Dyer. (*Amer. Foundryman*, 1952, **22**, Oct., 75–76). A table shows that even distilled water may have 44 parts per million by weight of solids, though other sources of American water contain up to 477 parts. Another table shows the consequent slight variation of green strength of wet bentonite.—E. T. L.

**Trends in the Usage of Core Sands.** W. M. Dummett. (*Australian Found. Trade J.*, 1952, **4**, Oct., 3–15). The author discusses several factors affecting the choice of core binders.—P. M. C.

**Hopper, Conveyor and Silo Replace Yard Gang.** E. H. Taylor. (*Iron Age*, 1952, **170**, Oct. 23, 105–106). Unloading from railway wagons and storage of core sand have been greatly simplified in the layout described. A conveyor belt is used to convey the unloaded material under cover to a 300-ton silo. The material is kept free running by being purchased dry and thereafter kept under cover.—A. M. F.

**Patterns—Their Relation to Castings Procedure.** T. H. Trevithick. (*Foundry*, 1952, **80**, Nov., 241–244). The author defines and explains the uses of the various types of pattern—one piece, two-piece, matched patterns, skeletons and sweeps, and the use of chaplets for mechanical support.

**Moulding and Feeding Steel Castings.** A. Ferro. (*Fonderia Ital.*, 1952, **1**, Dec., 233–238). The author describes steel casting techniques used at the Brescia steel and tube works and draws attention to problems when making steel castings from 50 lb. to 40 tons with carbon contents ranging from 0·15 to 0·35%. Details are given on pattern design, drying of moulds, methods of pouring and riser design, and on the solidification and contraction of steels.—M. D. J. B.

**Principles of Gating.** G. Martin. (*Foundry Trade J.*, 1953, **94**, Jan. 8, 63–69). The attempts which have been made to investigate the basic principles of the gating of castings are reviewed. The investigations are grouped into those studying turbulence effects and those concerned with the rate of flow through the gating system in relation to its dimensions. (58 references).—L. E. W.

**Core-Assembly as a Production Aid to the Jobbing Founder.** E. H. Beech and J. Hoyes. (Inst. British Foundrymen : *Foundry Trade J.*, 1953, **94**, Jan. 8, 33–39 ; Jan. 15, 71–78). The problems of the jobbing founder are briefly discussed and the foundry with which the authors are connected is described. Well-illustrated examples of core assembly are given to show how planning for core assembly may help to overcome difficulties arising from the lack of skilled craftsmen and the continued insistence for greater output of intricate castings.

**How to Make a Mold for a Pulley Casting.** P. Dwyer. (*Foundry*, 1952, **80**, Sept., 223–228 ; Oct., 229–234). Practical advice is given on making the pattern in a jobbing foundry, making a loam or sand mould, and preparation of the casting pit.—E. T. L.

**Shell Moulding: New Machine Makes it Automatic.** (*Steel*, 1952, **131**, Oct. 6, 83–86). An automatic shell moulding machine developed by the Metal Products Corp. of America is described. Occupying a floor space of about 150 sq. ft., die sizes up to 12 × 18 in. can be accommodated.—A. M. F.

**Shell Molding.** N. G. Chakrabarty and A. T. Vaswani. (Inst. Indian Foundrymen : *Metal Market Rev.*, 1952, **5**, Nov. 15–16).

**Report for Foundrymen—On Steel Castings by the Shell Moulding Process.** M. J. Sargeaunt. (*Brit. Steelmaker*, 1953, **19**, Jan., 26–29). In shell moulding, a heated pattern is invested with a sand-resin mixture which fuses to give a thin shell used in place of the normal sand mould. The author describes the process, which can be used for non-ferrous metals and alloy and carbon steels, the process being exactly similar in each case. The advantages claimed include excellent surface finish and dimensional accuracy, homogeneity in the casting, and virtual self-stripping as the mould disintegrates shortly after the casting freezes.—G. F.

**Revolution in the Foundry.** (*Canad. Metals*, 1952, **15**, Aug., 40–41). This paper summarizes the advantages and disadvantages claimed for the Croning shell moulding process. The initial costs of the airing ovens required are very high. The greatest advantages are the great reduction in sand required and cleaner castings obtained.—J. C. B.

**Shell Molding At International Harvester Co.** G. P. Phillips. (*Foundry*, 1952, **80**, Nov. 102–107, 282–292 ; Dec., 96–101, 177, 182). The contour moulding process is described in detail. A powdered phenol-formaldehyde resin is used with sand to make a soft shell $\frac{3}{8}$-in. thick. The tolerance possible is about 0·003 in., and the process is clean and economical. The author discusses pattern assembly, the choise of sand and resin, practical details of making the shells and cores, and the importance of control of pattern heating and of avoiding undercuring.—E. T. L.

**Shell-Moulding Developments.** (*Foundry Trade J.*, 1952, **93**, Dec. 4, 647–650). The technique is briefly described and illustrated. A heated pattern plate is brushed with a stripping solution, and then clamped over a box. The whole is then reversed, tipping sand on the plate, which thus becomes covered with a thin layer of sand-resin mixture, which is cured on the plate and then stripped off, giving a thin, strong mould. The method is much cheaper than hand-moulding, and the castings are less subject to chilling.—E. T. L.

**Notes on the Manufacture of Cast Iron Pipes.** H. J. Starns. (*Gas World*, 1953, **137**, Jan., 139–141). The activities at the testing laboratories of the Staveley Iron and Chemical Co. Ltd., are briefly summarized. The three methods of producing cast iron pipes are described. They are vertically or pit-cast, centrifugally cast by the sand spun process, or centrifugally cast in steel moulds, these being known as metal spun pipes. Jointing is described, with particular reference to the development of flexible joints.—T. E. D.

**Use of Cast Metal Offers Important Savings for Limited Manufacture.** F. Charity. (*Western Metals*, 1952, **10**, Mar., 41–43). The author discusses the merits of cast metal moulds and dies for manufacture of metal, plastic, rubber and leather products. The cost is much less than for machined or hobbed tools.—P. M. C.

## HEATING FURNACES AND SOAKING PITS

**Heating Steel in a Specialty Mill.** L. F. Van Mater. (*Iron Steel Eng.*, 1952, **29**, Nov., 74–76). The author discusses the general heating procedure in a speciality mill of relatively small tonnage with a wide range of products. The heating of ingots, billets and sheet is examined as well as the annealing of hot rolled stock and the thermal treatment of cold rolled products.—M. D. J. B.

**The Problem of Formation and Removal of Scale in Reheating Furnaces.** E. Terlecki. (*Hutnik* (Katowice), 1952, **19**, 11, 388–391). [In Polish]. Fast heating of ingots of steel containing up to 0·35% of carbon to a temperature about 1370° C. is recommended. The following advantages for fast heating to high temperatures are claimed : (1) Scale formation, decarburization, and diffusion of gases into the ingots are diminished ; (2) when 1370° C. is reached in the latter stages of heating, scale is melted and flows from the ingot, thus leaving a clean surface for rolling plate free from scale inclusions ; (3) higher plasticity of metal heated to a higher temperature facilitates rolling, producing plate with better strength properties than when the ingot is only heated to 1200–1250° C. ; and (4) when cold ingots are placed into a hot furnace, the temperature variations of the furnace lining are smaller with the consequent improvement of refractory life.

**Experiences with the Conversion of Reheating Furnaces from Coke-Oven Gas to Oil Firing.** T. Narjes. (*Stahl u. Eisen*, 1952, **72**, Dec. 18, 1658–1661). Oil storage plant and different types of burners are described and some practical experiences with fuel oil are reported. Under some conditions, non-insulated containers, *e.g.* unused blast heating stoves, can be used for reserve storage ; only the exits need keeping warm with a heating coil. It is then necessary only

to insert a small intermediate heater before the burner to bring the oil to the requisite temperature. Burners with pressure atomization give a longer and more controllable flame but are susceptible to trouble.—J. P.

**Organization of a Test on a Slab Reheating Furnace for Heavy Plates.** E. Giberti. (*Calore*, 1952, **23,** Oct., 529–539). [In Italian]. This paper gives a detailed description of an efficiency and fuel consumption test carried out on a reheating furnace used to heat 4-ton slabs. The tests, which were planned to eliminate sources of error and to isolate specific factors, have made possible correlation between theoretical computations and practical measurements.—M. D. J. B.

**Low Frequency Induction Heater.** (*Metallurgia*, 1952, **46,** Dec., 281–282 ; *Metal Treatment and Drop Forging*, 1952, **19,** Dec., 531–532). A 50-cycle induction heater for heating stock before hot working is described. It will heat 8–9 lb. of light alloy billets to 450° C. per kWH., and the heat efficiency is 45–50%.—B. G. B.

**High-Speed End Heating of Sucker Rods for Upsetting.** D. R. Dale. (*Metal Progress*, 1952, **62,** Oct., 115–117, 194). A gas-fired furnace for the controlled heating of the ends of sucker rods is described. Careful control of the process is essential. The steel used contains 3·5% Ni and 1·5% Cr.

**Cost Analysis in Industrial Heating.** B. W. Depew. (*Indust. Heating*, 1952, **19,** Oct., 1802–1814). A guide for cost analysis of industrial heating processes, which lists 13 different items of cost, is given. To illustrate its use several applications to metallurgical operations are discussed. These include annealing of malleable iron castings, furnace brazing, hot dip galvanizing, and heating for forging.—B. G. B.

**The Design and Calibration of a Pitot Tube for Hot Gas at Low Velocities.** R. D. Collins. (*Instrument Practice*, 1952, **7,** Nov., 39–46). This instrument was designed for the measurement of gas velocities in a steelworks soaking pit. In these conditions, a major difficulty is the measurement of gas of a high kinematic viscosity at a low velocity. A disc type velometer was used, as having the most suitable characteristics. Constructional details of the water-cooled velometer are given.—L. H.

## HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

**Selection and Treatment of Die Steels.** S. G. Fletcher. (Amer. Soc. Tool Eng. : *Steel Processing*, 1952, **38,** Oct., 513–516, 524, 525 ; Nov., 570–573, 578). A general review of the problems of correct selection and heat-treatment of die steels for different applications is presented. Compositions, applications, and treatments of conventional water, oil, and air hardening steels are discussed.—P. M. C.

**Automatic Heat Treating Line with Duplex Quench—Either Oil or Water.** F. C. Schaefer and R. L. Burdsall. (*Metal Progress*, 1952, **62,** Nov., 113–116). A description is given of a heat-treating unit for use with nuts, bolts and screws which is fitted with twin automatic quench tanks (one with oil, the other water). This unit is able to meet changing specifications of orders without a major change in the plant layout.—B. G. B.

**Versatile Pit Furnace.** A. H. Koch. (*Metal Treating*, 1952, **3,** Sept.–Oct., 2, 3). A new vertical muffle-type gas furnace by Surface Combustion Corp., Ohio, is described. The main parts of the furnace, quench tanks, motors for atmosphere circulation, are below floor level, allowing easier operation. The charge basket is 2 ft. in dia. by 3 ft. deep, and charges average between 700 and 800 lb. of steel. The plant can be used for almost any type of heat-treatment, including carburizing, hardening, and tempering.—P. M. C.

**Electric Furnaces in the Laboratories of IRSID at Saint Germain-en-Laye.** (*J. Four Elect.*, 1952, **61,** Nov.–Dec., 161–163). Several different furnaces have been installed in these new laboratories of IRSID. These include H.F. furnaces for melting between 5 and 300 kg. of iron, and muffle furnaces for use in the study of the heat-treatment of metals.—B. G. B.

**Carbon Content Determines Boron Steel Behaviour.** A. S. Jameson. (*Steel*, 1952, **131,** Oct. 13, 154–156). The majority of the heat-treated parts at the International Harvester Co. are now produced in boron steels. The difficulties that arise with low-carbon carburizing grades and the high carbon grades are discussed.—A. M. F.

**" Migration " of Copper Plating in Box Carburising.** T. W. Ruffle and P. M. H. Chawner. (*Metal Treatment and Drop Forg.*, 1952, **19,** June, 245–250, 254). The authors describe carburizing troubles met with near copper-plated, ' stopped-off ' zones on steel components. The case-hardening does not develop adjacent to the plated areas, and possible causes are put forward.—P. M. C.

**Carburizing of Steels.** J. L. Everhart. (*Mat. Methods*, 1952, **36,** Oct., 135–150). A comprehensive description is given of carburizing methods and equipment for pack, gaseous, and liquid methods. Heat-treatment, properties, defects, and applications of carburized components are dealt with.—P. M. C.

**On the Physico-Chemical Research of the Metallurgical Reactions of Charcoal (3rd Report). The Equilibrium Composition of Semi-Water Gas.** S. Uchida. (*Nippon Kinzoku Gakkai-Si*, 1952, **17,** Mar., 157–160). [In Japanese]. The equilibrium concentrations of $CO_2$, CO, $H_2O$, and $N_2$ in semi-water gas for the heat-treatment of steels are calculated and compared with those found in practice.—K. E. J.

**On the Physico-Chemical Research of the Metallurgical Reaction of Charcoal. (4th Report). On the Reaction of the Steels with Semi-Water Gas.** S. Uchida. (*Nippon Kinzoku Gakkai Si*, 1952, **16,** Mar., 161–164). [In Japanese]. Semi-water gas was investigated for bright annealing and carburizing of steels. When $CO_2$ and $H_2O$ contents were small, carburization occurred strongly : at low temperatures, carbon deposition occurred. (11 references).—K. E. J.

**On the Physico-Chemical Research of Charcoal for the Metallurgical Reaction. (5th Report). The Effect of Special Gases on the Reaction of Charcoal Gas for Steels. (1) The Effect of $H_2S$.** S. Uchida. (*Nippon Kinzoku Gakkai-Si*, 1952, **16,** June, 338–342). [In Japanese]. $H_2S$ was incorporated in gases for carburizing. Attack by $H_2S$ is reduced by increasing the carbon present. Attack is more severe by the CO–$N_2$–$H_2S$ mixture than by CO–$H_2$–$CH_4$–$N_2$–$H_2S$. The FeS scale contains some free Fe, due to diffusion. Carburization is less effective when the FeS scale has formed.—K. E. J.

**Metallurgical Study of Induction Surface Hardening. (1st Report). The Effect of Carbon on Hardness, Strain and Residual Stress of Carbon Steel.** T. Takase and Y. Mitani. (*Nippon Kinzoku Gakkai-Si*, 1952, **16,** Feb., 117–121). [In Japanese]. The induction surface hardening method has made rapid progress in Japan. Studies were made on 10 grades of steel (from 0·10 to 0·92% C). Preparatory heat-treatment to permit ready Fe–C diffusion is emphasized. Microhardness testing showed a fine, high carbon martensite in a transition zone, with higher hardness than the surface. The amount of martensite, and strain and residual stress, increase as carbon content increases.—K. E. J.

**Induction Hardening of Automobile Axle Shafts.** T. Bishop. (*Metal Treatment and Drop Forg.*, 1952, **19,** Oct., 439, 440). Details are given of a new heating unit installed at the Luton works of Vauxhall Motors Ltd. The EFCO unit deals with shafts 2 ft. 6 in. long by 1 in. in dia. and after quenching, a hardened case approx. $\frac{1}{8}$ in. deep is obtained. Two such units deal with 60 shafts/hr.—P. M. C.

**High Frequency Hardening of Steel.** (*Aciers Fins Spec. Franç.*, 1952, Dec., 46–50). The high-frequency tempering of steel is of French origin since it was patented in France by Fourment in 1925. The article deals with the basic principle of the method, heating units, inductors, suitability of steels for high-frequency heat-treatment, and comments on the action of induced currents.—E. C. S.

**Induction Heating in Engineering Production.** W. J. G. Cosgrave. (*Iron Coal Trades Rev.*, 1952, **165,** Oct. 10, 803–808). A general survey is given of the different types of work which can be undertaken for production heat-treatment by electric induction heating, and the outputs and limitations for typical components, including pins, shafts, track rollers and links, gears, and camshafts, are outlined. Particular attention is given to hardening by induction heating. Plant developed by the Electric Furnace Co. Ltd. for these purposes is briefly described.—G. F.

**Induction Hardening of Boron Steel Gears.** G. Van Camp. (*Mat. Methods*, 1952, **36,** Nov., 121, 122). The equipment and technique developed for a specific gear-teeth hardening operation are described. The gears, weighing 460 lb., are 28$\frac{1}{2}$ in. outside dia. and 5 in. wide across the face of the teeth. The steel is plain carbon composition, containing a little manganese and boron to increase the hardenability.—P. M. C.

**Enriching the Surface of Unalloyed Steel with Tungsten or Molybdenum from Salt Baths.** E. Fitzer. (*Arch. Eisen-*

*Hüttenwesen*, 1952, **23**, Sept.–Oct., 369–375). The surface enrichment of iron or steel with tungsten or molybdenum by reduction of a molten bath of sodium tungstate or molybdate by hydrogen has been carried out and the ensuing reactions between the metals and iron were followed. A new experimental procedure allowed the diffusion rates of the metals to be determined. From the diffusion coefficients, the depth of the diffusion layer can be predetermined. The most suitable conditions for producing tungsten- or molybdenum-rich surface layers have been worked out. The greatest penetration is obtained in very low carbon steel.—J. P.

**Carburizing, Nitriding and Siliconizing Tungsten- and Molybdenum-Rich Surface Layers on Iron.** E. Fitzer. (*Arch. Eisenhüttenwesen*, 1952, **23**, Sept.–Oct., 377–382). Carburizing tests on low carbon iron or steel, the surfaces of which had been enriched with tungsten or molybdenum, have shown that the ferritic surface layers can be carburized and that the underlying core can simultaneously take up carbon to hypereutectoid contents. The surface layers have great hardness, resistance to heat, and good wear resistance. Nitriding a molybdenized surface also increases the surface hardness and the best conditions have been worked out. Nitrided molybdenum layers are stable up to 500° C. Although simultaneous molybdenizing and nitriding by using ammonia as reducing agent for the molten sodium molybdate is not possible, it is feasible to carry out the reactions consecutively in one apparatus. This treatment is of interest principally for small articles such as gear wheels, valves, tools, and gauges. Siliconizing of a molybdenum diffusion layer produces a composite in which an iron-molybdenum-silicon layer next to the iron affords protection from acid attack although the iron silicide outer layer may be porous and cracked.—J. P.

**The Annealing of Steel.** J. Lomas. (*Brit. Steelmaker*, 1953, **19**, Jan., 30–35). The author presents a detailed examination of the principles of the annealing of steel, and describes the most efficient practice. Specific recommendations for annealing various materials are given, and brief mention is made of salt-bath annealing of stainless steels.—G. F.

**Annealing of Cold Rolled Strip.** (*Metal Treatment and Drop Forg.*, 1952, **19**, Oct., 443, 444). Brief details are given of the oil-fired portable-cover type furnaces used at the Trostre works of the Steel Company of Wales. The installation comprises five 8-stack cover furnaces and twelve 8-pedestal bases, and has a capacity of 5250 tons of 15,000-lb. coils/week.—P. M. C.

**Contribution to the Study of the Annealing of Steels at Rapid Rates.** A. H. Michel and J. Papier. (*Compt. Rend.*, 1952, **235**, Dec. 1, 1398–1400). The austenite in drastically quenched steels is generally only decomposed above about 500° C., but a differential dilatometric study reveals that at reheating rates of 250° C./hr. decomposition may occur between 270 and 300° C.—A. G.

**Fundamental Considerations on the Annealing of Cold Rolled Steel Strip.** A. Pomp. (*Stahl u. Eisen*, 1953, **73**, Jan. 29, 133–138). A review is presented of present knowledge of the annealing of cold rolled strip.—J. P.

**Experiences with Four-Chamber Pot Annealing Furnaces.** W. Feige and A. Neuhaus. (*Stahl u. Eisen*, 1953, **73**, Jan. 29, 139–147). The efficiency of annealing furnaces of a new clover-leaf design has been proved in three years' operation on coils of low carbon steel strip. The deep drawing properties of the outer layers of the coils were not affected by brief overheating, but uniformity of microstructure could be maintained only with low outputs. The use of waste and protective gas circulation resulted in increased output and more uniform temperature distribution through the coils. Under these conditions, a comparatively small furnace could reach outputs of 1·2 tons/hr. The use of heat-conducting plates is worth while only with strip widths over 1800 mm.—J. P.

**Design, Operation, and Results of an Electrically Heated Continuous Roller-Hearth Annealing Furnace for Coils of Cold Rolled Strip.** J. Keutmann and H. M. Junius. (*Stahl u. Eisen*, 1953, **73**, Jan. 29, 147–158). After comparing the usual annealing processes in cold rolling mills, a new method is described, in which narrow coils are continuously annealed by heating from the strip edges. The furnace is described and operational and economic data are given. The quality of the strip is fully equal to that of pot-annealed material although output is much greater.—J. P.

**Design and Operation of Bell-Type Annealing Furnaces with Circulating Protective Atmosphere and Heat-Conducting Plates.** O. Meurer, H. Fechner, and H. Pannek. (*Stahl u. Eisen*, 1953, **73**, Jan. 29, 158–165). Based on the knowledge that economic heat flow when annealing strip coils is possible only from the edges of the strip, a circulating process has been developed in which heat conducting plates (spiral convectors) are placed between the individual coils. In this way, the fan, built into the furnace base, can circulate protective gas around each coil with high velocity and thus carry the heat rapidly and uniformly to the steel. The design of the first unit is described and operational data are given for the first three plants of the type. The heat consumption was approximately 230,000 calories per metric ton.—J. P.

**Heat Treatment Oils.** A. L. H. Perry. (*Metal Treatment and Drop Forg.*, 1952, **19**, Nov., 467–473, 482). The various types of fatty and mineral oils, used for quenching and tempering, are considered with reference to their origin, suitability, and deterioration. The testing and evaluation of quenching power by hardenability tests and cooling curves are described, and some advice on handling, heat exchange systems, and cooling equipment is given.—P. M. C.

**Armour Plate Quenched Rapidly, Uniformly in Hydraulic Press.** G. A. Leytze. (*Iron Age*, 1952, **170**, Oct. 16, 97–99). Plates ranging from ¼ to 3 in. thick are quenched in a 2500-ton hydraulic press to maintain flatness. Dies are designed to achieve a rapid and uniform quench over the entire surface area of the plate which can be up to 70 × 200 in. in size. The unit is located between the hardening and tempering furnaces and all handling is done on roller conveyors. Total pressure applied can be varied to suit different sizes and thicknesses.

**Studies on Quenching Media. 4th Report. The Cooling Abilities of Water and Aqueous Liquids.** M. Tagaya and I. Tamura. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, Feb., 107–111). [In Japanese]. Cooling properties of aqueous solutions of many acids, bases and salts, and colloidal dispersions, have been studied. With non-volatile solutes, cooling is rapid in the pearlite stage and slow in the martensite stage: the reverse applies for colloidal solutions.—K. E. J.

**Studies on the Quenching Media. (5th Report). The Cooling Abilities of Fatty Oils.** M. Tagaya and I. Tamura. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, June, 342–346). [In Japanese]. For quenching oils, the characteristic temperature should be raised, and the temperature of commencement of convection lowered. These temperatures, chemical properties and cooling properties are described for a range of fatty oils.—K. E. J.

## FORGING, STAMPING, DRAWING, AND PRESSING

**Drop-Forging Practice in Australia.** H. J. Merchant. (*Metal Treatment and Drop Forg.*, 1952, **19**, Aug., 335–341; Sept., 405–411, 417). The second World War and the growth of aircraft, automobile, and other industries have instigated a great advance in the drop-forging industry in Australia. There exists today a market and production facilities for at least 200 tons per week of forgings and drop forgings of all kinds. The author surveys the progress made and describes the facilities, equipment, layout, and practice at the works of the Australian Forge and Engineering Pty. Ltd. The production organization, inspection control, and machine maintenance methods are described, and some typical types of forging and their production rates are discussed.—P. M. C.

**Die Sinking By Drop Forging.** A. Rohrmann. (*Steel Processing*, 1952, **38**, Aug., 375–381; Oct., 503–509; Nov., 561–568, 578, 579). Hot die typing or hobbing is now being used successfully as a method of lowering forging die costs. Dies are sunk by using a master replica of the part to be produced. Die inserts are used extensively to minimize the amount of replaceable material. The problems associated with shrinkage allowances and methods of setting and aligning inserts are discussed. The heating, protection from scaling, and forging of such dies is described, and methods of securing inserts in their holders are outlined.—P. M. C.

**Tools for Clipping Drop Forgings.** (*Metal Treatment and Drop Forg.*, 1952, **19**, July, 313–318). A sub-committee set up by the National Association of Drop Forgers and Stampers has investigated current practices in the design and composition of steels used in the construction of tools for removing flash from drop forgings. Their recommendations for steel compositions for different types of punches and beds are given in this article.—P. M. C.

**Shearing for Drop-Forging.** A. Billingham. (*Metal Treatment and Drop Forg.*, 1952, **19,** Oct., 453–458). The author discusses the nature of shearing, press capacity, design and care of blades, clearance, and types of steels which can be cut satisfactorily. The suggestion is made that, provided sufficient care and common sense are used, a spare clipping press can be utilized advantageously with fairly simple tools.

**Design of Forging Machine Tools.** E. W. Mace. (*Metal Treatment and Drop Forg.*, 1952, **19,** June, 263, 264, 274). A brief outline is given of the calculations and principles involved in designing the tools required for the upset forging of an axle shaft in five operations.—P. M. C.

**Dodge Forge Introduces a "First" in the Forging Industry.** J. C. McComb. (*Steel Processing*, 1952, **38,** Oct., 497–502, 517, 518, 523). A new highly automatic production line has been installed by the Chrysler Corp. for the press forging of automotive crankshafts at the rate of 150/hr. Billets 4 × 4 in. × 2 ft. long are heated in a 30-ft. rotary hearth furnace, descaled, preformed by reducer rolls, forged under a 6000-ton mechanical press, trimmed, twisted, quenched and tempered. A full description and illustrations of the plant are given.

**Press Plant—An Interesting Development by the Chrysler Corporation.** (*Automobile Eng.*, 1952, **42,** Dec., 527–528). See preceding abstract.

**Automated Forging Line Boosts Output, Cuts Costs.** W. G. Patton. (*Iron Age*, 1952, **170,** Oct. 2, 93–96). The new continuous press forging installation for crankshafts at the Chrysler works is described.—R. A. R.

**New Lubricant Improves Die Life, and Finish.** W. E. Curtiss. (*Iron Age*, 1952, **170,** Oct. 30, 94–95). The use of Metalloid X-60 as a die lubricant is claimed to have increased the life of hard chromium-plated dies from 1000 to 11,800 pieces between dressing. The operation consists of drawing a 6·5-in. deep, 3-in. dia. shell from 0·065 in. annealed blanks of 0·10% carbon steel.—A. M. F.

**"Impacting"—A Revolutionary New Forging Process.** H. C. Hood. (*Steel Processing*, 1952, **38,** Nov., 553–555, 569). A new method for the automatic mass production of die forgings has been developed by the Chambersburg Engineering Co., and designated "Cecomatic Impacting". The impact machine consists of two horizontally opposed, air-driven hammers, the impact energies of which are completely absorbed by the stock which is suspended in the impact plane. Electronic devices are employed to ensure that the opposing dies always hit the stock simultaneously. Jet engine turbine blades and other such parts are being made by this method, for which is claimed better grain flow, less vibration, less flashing, longer die life, and heating and power economies, compared with drop hammer forging.—P. M. C.

**Crankshaft Output Tripled.** H. C. Tuttle. (*Steel*, 1952, **131,** Sept. 29, 78–81). The completely mechanized forging installation at the Chrysler works is described. The continuous press forging of automobile crankshafts has replaced hammer forging and the output has been considerably increased. Conveyors play a leading part in taking the billets through shearing, heating furnace, descaler, and forging operations.—A. M. F.

**Large Forgings Will Slash Fabrication Costs.** (*Iron Age*, 1952, **170,** Sept. 25, 128–130). It is shown how the use of heavy presses to produce forgings for the aircraft industry can do much to permit weight reductions and increase structural strength. The trend in aircraft design is away from building up structures from small parts and this gives a corresponding cost saving in assembly.—A. M. F.

**Forging Dies Finished, Maintained by Wet Blasting.** E. F. Anderson. (*Iron Age*, 1952, **170,** Sept. 18, 160–162). A wet blasting process which consists of hurling at high velocity, very small abrasive particles in a water suspension, leaves a matt surface on the die. This type of surface has the advantages of easy release of a formed part and the ability to hold lubricants well. It is claimed to be much more efficient than other methods of die finishing and tolerances, sharp corners, and lines are not affected.—A. M. F.

**Wyman-Gordon Co. Leader in Aircraft Forging.** J. C. McComb. (*Steel Processing*, 1952, **38,** Sept., 435–455; Oct., 510–512). A description is presented of the equipment, products, and procedures at the North Grafton and Worcester plants of the Wyman-Gordon Co. The former houses an 18,000-ton Mesta, a 7700-ton Schloemann, and a 1500-ton Wood press. Loewy Hydropress units of 35,000 and 50,000 tons are to be installed in the near future. Stages in the production of large aircraft forgings are outlined. At the Worcester plant, miscellaneous steel and light alloy drop forgings are produced by 36 hammers ranging from 2500 to 25,000 lb. capacity. Eight mechanical and hydraulic presses, and a special 7200-ton Farquhar press are used for extrusion operations and for hollow forging. The production of landing gear cylinders from 850-lb. billets, turbine wheels, and magnesium alloy fan blades are described.—P. M. C.

**Tripled Pressure with One Tenth Weight Achieved by New Douglas-Built Hydropress.** (*Western Metals*, 1952, **10,** May, 36, 37). The development of a revolutionary new type of hydraulic press for shallow forming of sheet metal components at the Douglas Aircraft Co., is described. The method is a modification of the Guérin process, the rubber forming pad being replaced by direct hydraulic pressure.—P. M. C.

**Heavy Presses Challenge Industry.** A. Zietlin. (*Steel*, 1952, **131,** Dec. 1, 76–79). Heavy presses for forging and extrusion now being built in the U.S.A. are reviewed. These giant machines require new concepts in design, materials, foundations, construction methods, control, operation and production techniques. A description is given of the 50,000 and 35,000 ton hydraulic forging presses and auxiliary plant.

**Forging on the Fly.** (*Steel*, 1952, **131,** Dec. 1, 89, 102). A new horizontal drop forge machine (the 'Impacter') in which both dies strike the stock, is described. Advantages are improved grain flow, absence of shock and vibration, and suitability for use in automatic systems. The machines can be used for hot or cold working.—D. L. C. P.

**Plastic Dies Draw Truck Panels.** H. C. Tuttle. (*Steel*, 1952, **131,** Sept. 15, 92–93). In the Chrysler press plant, Detroit, a new material is being used for dies. This is a thermosetting liquid phenolic casting resin with considerable dimensional stability.—A. M. F.

**Investigation on the Force and Amount of Work Required when Cold Pressing Various Steels.** H. D. Feldmann. (*Stahl u. Eisen*, 1953, **73,** Jan. 29, 165–174). Existing formulæ for calculating force and work in plastic deformation have been applied to three types of cold pressing. The force was measured with an electrical device employing a type of differential condenser. The degree of deformation lay between 35 and 85%. Pressing speed influences the force required according to the amount of deformation. The three types of pressing can be compared using the concept of displaced volume and a general force calculation is employed. Cold flow was studied by the engraved reticule method on split banks.—J. P.

**Shaping Sheet Metal by Pressing and Stamping.** M. Caffin. (*Ossature Métallique*, 1952, **17,** Oct., 473–478). The author surveys the methods available for applying various types of corrugation to sheet metal.—P. F.

**Conveyor Network Moves Press Scrap.** H. C. Tuttle. (*Steel*, 1952, **131,** Dec. 8, 100–101). The article describes a mechanized installation for collection and baling of press scrap which can handle up to 220 tons/day. Collecting belts pass under the presses and discharge onto a main conveyor, which runs into the baler house.—D. L. C. P.

**Rheem's New Hot Cupping and Cold Drawing Cuts Critical Steel in Artillery Ports.** F. J. Wood. (*Western Metals*, 1952, **10,** June, 39–41). A new manufacturing sequence for 81-mm. mortar shells is described. A 5·2-lb. steel billet produces a finished shell weighing 4·29 lb., representing a saving of about 3 lb. per shell compared with previous methods. The hot forging and cold drawing operations are briefly outlined. Great emphasis is placed on the use of phosphate coatings and correct lubrication, which permit cold reductions of 90 to 100% between anneals.—P. M. C.

**Thread Rolled Drop Hammer Die Studs Cut Setup Delays at Douglas Aircraft.** (*Western Metals*, 1952, **10,** Apr., 57, 58). Longer life is obtained from drop hammer die studs which are roll rather than machine threaded. The studs are in SAE 4340 Steel, 1 in. in dia. × 20 in. long, and have an eight-pitch threaded length at each end. The rolling of threads of such size requires an unusually large machine, in this case a Reed A–33, which can roll threads on stock up to 5½ in. in dia.

**An Experimental Investigation of the Yielding of Strip Between Smooth Dies.** A. B. Watts and H. Ford. (*Inst. Mech. Eng., Preprint*, Dec. 5, 1952). Copper strip was indented between smooth rigid flat dies, the die breadth $b$ and material thickness $t$ being varied to cover the range of $t/b$ from 12 to $\frac{1}{4}$. The mean pressure on the dies when yielding occurs depends upon the $t/b$ ratio, the form of the solution

to the problem being different above and below the value $t/b = 1$.—P. M. C.

**An Experimental Investigation into the Redrawing of Cylindrical Shells.** S. Y. Chung and H. W. Swift. (*Inst. Mech. Engs. Preprint*, Dec. 5, 1952). Details are given of experimental investigations into the forces, work, and strains involved in direct and reverse redrawing of brass, aluminium, and mild steel. The conditions examined included first-stage drawing ratio, inter-stage heat-treatment, punch profile radius, first stage punch-die clearance, redrawing ratio, and blank thickness. The reverse redrawing method was superior to the direct one when the severity of bending was the same in both, but the direct method can be designed to give a larger die-profile radius and may, under favourable conditions, yield a better drawing capacity. The maximum combined drawing capacity over two stages was obtained when using the maximum first-stage blank size.—P. M. C.

**How to Fabricate 17 Percent Chromium Stainless Steel.** R. E. Paret. (*Mat. Methods*, 1952, **36,** Nov., 100–104). A straight 17%-Cr steel is being used more and more as a substitute for the nickel-bearing 302 type. Its fabricating properties are different, and notes on the drawing, spinning, bending, machining, and welding of both qualities are presented.—P. M. C.

**Special Steel Piercing Methods Appraised.** A. Williman and W. P. Wallace. (*Iron Age*, 1952, **170,** Oct. 30, 96–98). Two methods of piercing oil well casings to improve seepage are examined, these are by means of a steel bullet or a specially shaped charge. Tests were carried out on low carbon and high manganese steel plates ; the changes in microstructure in the latter were considerably less. The bullet gave a cleaner hole, but residual stresses in both cases were high.—A. M. F.

**Producing Large-Diameter Pipe to Exacting Specifications.** W. C. Hoppe. (Amer. Soc. Mech. Eng. : *Iron Age*, 1952, **170,** Sept. 25, 118–121). A description is given of the manufacture of 40-ft. lengths of piping in diameters from $8\frac{5}{8}$ to 36 in. Forming presses range in size from 3000 to 11,000 tons ; each 40-ft. length of pipe is flash-resistance welded in one operation. Accurate dimensions are secured by an internal expansion process before the final end facing operation is carried out.—A. M. F.

**The Extrusion of Steel.** (*Machinery Lloyd*, 1952, **24,** Nov. 15, 91–92). A brief description of the processes involved in the extrusion of metals is given. A few examples of extruded steel sections and their advantageous properties are discussed.

**Extrusion of Steel: Equipment, Operation, and Production.** J. Sejournet. (*Iron Coal Trades Rev.*, 1952, **165,** Oct. 31, 963–966). In discussing the underlying principles of the successful extrusion of steel, the author first considers briefly the types of equipment in use and possible future developments in press design. The various operations carried out are then described, and finally production rates and output are considered.—G. F.

## ROLLING-MILL PRACTICE

**Development of Segregation During Rolling.** Petitfrère. (Commission d'Ingénieurs : *Centre Doc. Sider. Circ. Inform. Tech.*, 1952, No. 1, 103–110). This paper is concerned with the deformation of the segregated zone in mild steel rimming ingots during rolling. Diagrams are given illustrating ; (1) The deformation during roughing down ; (2) rolling to produce a circular cross section ; (3) rolling of various profiles ; and (4) rolling of sheet.—T. E. D.

**Contribution to the Study of Defects in Rolling.** Nore. (Commission d'Ingénieurs : *Centre Doc. Sidér. Circ. Inform. Tech.*, 1952, No. 6, 851–853). The serious effects of superficial defects, such as striations, on the future forged or pressed products are emphasized. The recommended procedures to minimize the number of defects are fast rolling and the highest possible rolling temperature compatible with the nature of the steel.—T. E. D.

**Rolling of Freshly Cast Ingots.** Petitfrère. (Commission d'Ingénieurs : *Centre Doc. Sidér. Circ. Inform. Tech.*, 1952, No. 1, 93–102). Results of rolling trials performed, before the last war, on incompletely solidified ingots are reported. The ingots, to be used for rails, weighed about 4·5 tons, and contained 0·42% C, 0·90–1·0% Mn, 0·12% Si, 0·075% P and 0·04% S. Previous thermal history and rolling conditions are stated. Drawing and shock tests were performed, and results are given of analyses, hardness tests, and macrographic examinations of various zones within rails which were either newly rolled or broken in service. Solidification, crystallization and segregation in ingots are discussed by M. Grenier.—T. E. D.

**Progress in Rolling Mills.** J. d'Yerville. (*Arts et Manuf.*, 1953, Jan., 32–33). Recent advances in rolling plant are mentioned and some new installations in France are listed.

**Mercury Arc Rectifiers for Main Roll Drives.** H. E. Larson. (*Iron Steel Eng.*, 1952, **29,** Nov., 61–73). This paper examines the progress which has been made since 1939 in the application of rectifiers to main roll drives and gives the basic reasons why rectifiers are preferred to motor-generator sets for certain classes of mills.—M. D. J. B.

**Electric Brains Expand Steel's Muscle.** W. R. Harris. (*Steel*, 1952, **131,** Nov. 3, 106–115 ; Nov. 10, 112–126). The author considers the requirements of automatic regulating systems for modern main and auxiliary mill drives.—D. L. C. P.

**A Note on the Method of Using Sharp-Angled Rollers for Hot-Rolling of Steel T Sections.** L. Gascuel. (*Ossature Métallique*, 1952, **17,** Dec., 581–582).

**The Rolling of Angles.** J. Courtheoux. (Commission d'Ingénieurs : *Centre Doc. Sidér. Circ. Inform. Tech.*, 1952, No. 4, 534–535). European, English and American rolling practice are compared. The finishing of roll profile design is discussed with respect to the method of development, and amount of reduction at each pass. Three modern processes are compared and the advantages of each are discussed. Rail profiles are illustrated.—T. E. D.

**Communication on the Manufacture of Rails in French and Saar Works.** Stammbach. (Commission d'Ingénieurs: *Centre Doc. Sidér. Circ. Inform. Tech.*, 1952, No. 4, 530–533). The stages in the manufacture of rails are surveyed from the replies to a questionnaire to eight works. Details of practice with regard to ingot size, reheating, blooming mill operations, rolling, and cold finishing are discussed. The range of steel composition and variation in mechanical properties are quoted.—T. E. D.

**Mathematical Determination of Metal Flow in Regular Sections.** Z. Wusatowski and R. Wusatowski. (*Prace Inst. Metalurgii*, 1952, No. 4, 273–291). [In Polish]. Methods of calculating the mean reduction proposed by various authors are discussed. The present authors' method of calculating mean thickness and reduction for regular profiles is outlined. Z. Wusatowski's formula for spread and elongation using mean values is advocated, and the calculations of mean reduction and metal flow are verified by several rolling-mill trials.—V. G.

**Operation of a 12 in. Continuous Bar Mill.** A. H. Griffiths. (*Iron Steel Eng.*, 1952, **29,** Nov., 55–60). The author describes the Kansas City Plant of the Sheffield Steel Corp. The mill comprises 12 horizontal roll stands and 3 vertical edging mills. A feature is that, for rolling angles, the passes are all open, including the leader pass, using nine shape passes and three edging passes. This is a very economical layout because all the pass sizes are in one set of rolls excepting the leading and finishing.—M. D. J. B.

**Bearings in Large Rolling Mills in Belgium.** (*Ball Bearing J.*, 1952, No. 3, 53–57). Details are given of bearings in (1) a two-high mill with rolls $28\frac{1}{2}$ in. dia., (2) a two-high planishing mill with rolls $30\frac{1}{2}$ in. dia. and 55 in. barrel length, and (3) a four-high mill with work rolls $14\frac{1}{2}$ in. and back-up rolls 53 in. in dia. with a barrel length of 48 in.—R. A. R.

**The New Strip Mill at S.A. Métallurgique d'Esperance-Longdoz.** W. Pateisky. (*Stahl u. Eisen*, 1953, **73,** Jan. 29, 177–179). The lay-out of this new mill is illustrated and the hot rolling, pickling, cold rolling, and annealing equipment is described. Cold rolling is carried out with a Sendzimir reversing mill.—J. P.

**Electrical Equipment for Process Lines in Continuous Strip Mills.** R. G. Rayden. (*Sheet Metal Ind.*, 1952, **29,** June, 485–492, 500 ; Nov., 971–978). This article deals with electrolytic cleaning lines and gives details of motors, control gear, and control stations. Slitting and trimming lines, and the equipment required are also described.—P. M. C.

**Strip Width Held to Close Limits.** G. R. Petersen. (*Steel*, 1952, **131,** Sept. 29, 94–97). The Irvin Works of the United States Steel Co. are employing a strip width gauge to measure deviations in width of $\frac{1}{64}$ in. over a range of 10 to 96 in. Two scanning heads using the light radiated from the hot strip generate the measuring signals which compare the strip width with gauge settings ; deviations in width are then shown on an indicator.—A. M. F.

**Automatic Gauge Control of Strip Rolling: Development of New Instruments.** A. G. Thomson. (*Iron Coal Trades Rev.*, 1952, **165,** Nov. 14, 1077–1078). The author briefly describes two automatic methods of gauge control for strip rolling, which have been developed by B.I.S.R.A. to reduce gauge variations which are primarily due to the speed effect and to variations in the properties of the strip entering the mill. In both methods the mill is fitted with a loadmeter which automatically adjusts either the strip tension or the roll setting.—G. F.

**Handling and Reclaiming Mill Scale.** (*Iron Steel Eng.*, 1952, **29,** Nov., 138–139). This article describes a means of recovering 97% of the mill scale from a hot strip mill. The system consists in making the mill water go through settling tanks or concentrators from which the scale is recovered.

**The Forward Slip in Cold Strip Rolling.** R. B. Sims. (*Sheet Metal Ind.*, 1952, **29,** Oct., 869–877). During experimental research on the B.I.S.R.A. 10 in. × 10 in. 2-high mill, designed to determine the effect of combined strip tensions on the roll force and torque, a large number of measurements of forward slip were made. Measurements made without applied strip tensions varied considerably in magnitude although the rolling conditions were carefully controlled. This is probably due to changes in the frictional forces in the roll gap, friction being less variable with tension than without it. The experimental results are compared with theoretically derived equations, and a simpler method of computation is also proposed for the case of rolling with tensions, based on a semi-empirical relationship. (12 references).—P. M. C.

**Cold-Rolled Sheet Production at Abbey Works, Steel Company of Wales.** H. H. Ascough. (*Sheet Metal Ind.*, 1952, **29,** Oct., 878–881). The continuous pickle line, acid neutralizing plant, 3-stand cold-reduction mill, annealing plant, and temper mills are briefly described.—P. M. C.

**"Watch Charm" Mill Specializes on Small Diameter Butt-weld Pipe.** J. D. Knox. (*Steel*, 1952, **131,** Dec. 1, 90–101). A continuous mill for producing $\frac{1}{8}$, $\frac{1}{4}$ and $\frac{3}{8}$ in. dia. butt-welded tubes at 700 ft./min. is described; it takes coiled stock and turns out 18–22 ft. lengths of tubing. Subsequent plant allows final treatment and testing.—D. L. C. P.

**Electrical Engineering in the Steel-Tube Industry.** H. E. Knight. (*Proc. Inst. Elect. Eng.*, 1953, Part 1, **100,** Jan., 10–11). An outline of the electrical equipment required for various tube making processes is first given, *i.e.* the Fretz-Moon, electric-resistance-weld, Pilger, push-bench, and plug mill processes. The author then describes in more detail the layout and method of operating at the Corby Tube Works, Northants.—L. H.

**Multiple Generators for Processing Lines.** E. E. Vonada. (*Iron Steel Eng.*, 1952, **29,** Nov., 77–82). The author discusses in detail the advantages of providing multiple drives to high speed tandem mills. Circuit diagrams and voltage curves are given of an electrolytic tinning line equipped with a multiple generator system.—M. D. J. B.

**Some Roll Shop Problems.** J. H. Steele. (*Proc. Ebbw Vale Met. Soc.*, 1952, **2,** 65–75). The problems are those relating to the supply of rolls to R. Thomas and Baldwins Ebbw Vale mill. They include: (1) The choice of grinding wheel and abrasive; (2) 'chatter' and how to prevent it; (3) spiral lines left by the edge of the grinding wheel; and (4) shot-blasting difficulties.—R. A. R.

## MACHINERY FOR IRON AND STEEL PLANT

**Power for Steel Works.** J. R. Phillips. (*E.S.C. News*, 1952, **6,** 3, 2–8). A short history of the development of generating equipment used at the River Don Works of English Steel Corp. is given. This is followed by a more detailed account of the present power equipment.—J. C. B.

**Electric Cranes—Controlled Acceleration and Creep Speed Systems.** (*Elect. Rev.*, 1952, **151,** Dec. 5, 1217–1218). Two new control systems for electrically operated cranes are described. The Auto-Cam-Tactor system gives equivalent automatic acceleration to a magnetic contactor equipment, by means of a series-wound hold-in coil for each accelerated contractor with which is combined a series-wound sequence coil.The second is the Hilotrol creep system of hoist control.

**Modern Crane Control for Steel Plants.—Alternating Current.** W. R. Wickerham. (*Iron Steel Eng.*, 1952, **29,** Nov., 100–106). The author discusses A.C. crane control systems, dealing with mechanical and electrical load brakes, the counter-torque and A.C. dynamic systems.—R. A. R.

**Modern Crane Control for Steel Plants.—Direct Current.** G. E. Mathias. (*Iron Steel Eng.*, 1952, **29,** Nov., 106–111). The author reviews briefly the desirable features of D.C. control and explains why D.C. control is given preference in the steel industry. Details are given of D.C. adjustable voltage hoist control, characteristics of electrical equipment, hoist performance, and constructional features.—M. D. J. B.

**Code Interpretations and Conductor Selection for Cranes and Hoists.** L. Price. (*Iron Steel Eng.*, 1952, **29,** Nov., 130–136). The author examines the various codes of practice dating from 1930 to the present time. Comparative tables are given for allowable current carrying capacities of insulated contactors, dimensions of rubber-covered and thermoplastic-covered conductors and of motors.—M. D. J. B.

**New Wire Rope Gives Better Service.** (*Iron Age*, 1952, **170,** Sept. 25, 117). **Wire Rope Life Increased On Hot Metal Cranes.** W. C. Richards. (*Steel*, 1952, **131,** Sept. 29, 104–106). A flattened strand construction of steel cable is described. This permits the use of 10% more metal, and the keystone shape of strands together with a small core offers greater resistance to crushing. Much increased life is claimed under arduous conditions such as ladle cranes.

**The Technique of Plate Bending.** E. L. Tinley. (*Welding and Metal Fab.*, 1952, **20,** Oct., 356–360). In a plate-bending machine the material is passed between rolls which are so arranged that they bend the plate and stress it to a state of plastic yielding, the deformation being of sufficient magnitude to ensure that the required radius of curvature is imparted to it. Plate-bending machines of different sizes are described and illustrated.—U. E.

**Some Industrial Applications of Hydraulic Servos.** T. Brading and G. Parks. (*Inst. Mech. Eng. Conf. on Hydraulic Servo-Mechanism*, Feb. 13, 1953. *Advance Copy*). The authors describe several servo-mechanisms which have been developed for use with hydraulic transmission gears where automatic control is necessary in various industrial applications.—R. A. R.

**Cinder Pots Designed for Long Service.** (*Blast Furn. Steel Plant*, 1952, **40,** Dec., 1454–1455). A description of Johnston Steel slag ladles is given. These ladles have corrugated walls with convex sides which increase the rate of heat transfer and also allow for expansion and contraction. A copper coating on the inside lower portion prevents entrained metal from fusing to the bottom.—B. G. B.

## LUBRICANTS AND LUBRICATION

**Lubricants Must Survive Rough Treatment.** M. S. Clark. (*Steel*, 1952, **131,** Oct. 13, 228–250). Lubricants in steel mills have to function under conditions of high temperature and high mill operating speeds as well as being subjected to high-pressure water and scale in filtration. The breakdown of water emulsions and the cleaning of circulating oils are important problems. Methods of lubricating gears are described, and it is recommended that line shaft bevel gears for roller tables should be sprayed.—A. M. F.

**On the Energy Equation for Fluid-Film Lubrication.** A. Charnes, F. Osterle, and E. Saibel. (*Proc. Roy. Soc.*, 1952, **214A,** Aug. 7, 133–136). The energy equation for fluid-film lubrication is developed in such a way as to resolve the existing discrepancy in the literature between two different equations (one based on the 'dissipation function', the other on the equality of shear work on the lubricant with stored energy). A qualitative estimate of the error introduced when using the incorrect equation is given.—K. E. J.

**On the Solution of the Reynolds Equation for Slide-Bearing Lubrication—I.** A. Charnes and E. Saibel. (*Trans. Amer. Soc. Mech. Eng.*, 1952, **74,** July, 867–873).

**Plant Value Improved by Lubrication.** G. D. Jordan. (*Sci. Lubrication*, 1953, **5,** Jan., 13–17). Many items of old plant are performing necessary duties at low rates of production; lubrication can produce large benefits of productivity increase and reduction of running cost with a relatively small outlay. Suitable lubricants, methods of application, and plant design changes are discussed. The principles are illustrated from experience with a two-high hot rolling mill with roughing and finishing stands, of the United Steel Companies Ltd.—K. E. J.

**Oil Flow in Plain Journal Bearings.** S. A. McKee. (*Trans. Amer. Soc. Mech. Eng.*, 1952, **74,** July, 841–848). An analysis is given of the factors affecting the leakage of oil from the ends of plain journal bearings fed either through an oil-hole

or an axial groove on the unloaded side, or a circumferential groove. The data indicate that for any given bearing the oil flow may be expressed in terms of dimensionless factors involving the oil feed pressure and the bearing load.—D. H.

**Oil Flow, Key Factor in Sleeve-Bearing Performance.** D. F. Wilcock and M. Rosenblatt. (*Trans. Amer. Soc. Mech. Eng.*, 1952, **74**, July, 849–866). The paper is concerned mainly with the nature and quantitative determination of oil flow, and simplified methods for the calculation of bearing performance made possible thereby.—D. H.

**Effect of Variations in Viscosity of Lubricants upon Timken O.K. and P.s.i. Values.** I. S. Kolarik, C. A. Zeiler, and E. M. Kipp. (*Trans. Amer. Soc. Mech. Eng.*, 1952, **74**, July, 875–878). The paper describes an investigation carried out to determine the magnitude of hydrodynamic-lubrication effects associated with viscosity in determining O.K. loads (load in pounds divided by the failed area in square inches). The effect of rubbing speeds was also studied.—D. H.

**Electrochemical Reactions in Frictional Systems at High Temperatures, and Their Influence on Wear in Industrial Machines.** H. Schiffers. (*Metalloberfläche*, 1952, **6**, Aug., A120–A124). The author describes the chemical changes which take place in and between the lubricating oil film and the bearing surfaces at high temperatures, and emphasizes the electrochemical nature of these reactions.—L. H.

## WELDING AND FLAME-CUTTING

**Cast or Welded Construction?** O. Pleva. (*Technik*, 1952, **7**, June, 327–328). In comparing relative costs of cast and fabricated structures, the author compares the quantity of liquid steel needed in either case, as well as outputs by welders and foundrymen.—J. G. W.

**Application of the Micro-Mechanical Method to the Investigation of Zonal Properties in a Welded Joint.** M. E. Zaidman and I. M. Roitman. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 729–732). [In Russian]. Two 4-mm. thick plates of Chromansil steel were butt-welded and then cut into strips perpendicularly to the seam. From the strips, micro-specimens 0·8 mm. in dia. were cut out at various distances from the seam and parallel to it, and subjected to tensile tests before and after various heat-treatments. Hardness was also determined. From the results, the plasticity in tension of the different portions of a welded joint as well as their yield point and tensile strength were determined.—S. K.

**Progress in Welding and Cutting Methods. New Publications on the Metallurgy of Welded Iron and Steel.** (*Schweissen u. Schneiden*, 1952, **4**, Nov., 402–416). This is an extensive review of literature on metallurgical problems in the welding of iron and steel. (267 references).—U. E.

**A New Variation of Fusion Pressure Welding.** L. Knez. (*Schweisstechn.*, 1952, **6**, Sept., 101–106). The fusion pressure welding process as applied to the welding of rails in Yugoslavia is described. Both ends of the rail are heated to 1000° C. The steel is then carburized by the use of an acetylene flame, and, when the lower melting point of the ledeburitic iron layer is reached, pressure is applied. A post-heat-treatment is necessary for the carbon in the ledeburitic layer to diffuse to a pre-decarburized zone. The physical chemistry of the reactions when a neutral and a carburizing oxygen-acetylene flame is used is discussed. Metallurgical properties and the economic aspect of the process are dealt with.—U. E.

**"Pre" and "Post" Pressure Welding.** H. von Neuenkirchen. (*Schweissen u. Schneiden*, 1952, **4**, Oct., 360–361). These two pressure welding processes differ in so far that in the pre-pressure welding method high pressure is applied before maximum temperature is reached, and in the post-pressure method the order is reversed. A schematic diagram is given showing the relation of time to temperature and pressure.—U. E.

**Welding of New Steels Used at High Temperatures and Pressures.** F. Šícha and J. Jedlička. (*Hutnik* (Prague), 1952, **2**, 11, 472–477). [In Czech]. Methods and experimental results relating to welding of steels for high-pressure tubing, steam-turbines, and high-pressure steam fittings are discussed.

**The Welding of Tool Steels.** T. Norén. (*ESAB Revue*, 1952, No. 2, 1–12). [In French]. Various methods used for the repair of steel tools are described. The sequence of operations is: (1) Heating the base metal to its tempering temperature. (2) Cooling the tool to the temperature of welding (*i.e.*, at which the austenite transformation is slowest). The welding is carried out at this temperature. (3) Reheating the tool to the tempering temperature. (4) Cooling the tool as if for normal tempering of the base metal. (5) Reheating to a lower temperature. (6) Grinding the weld. The use of **S**-curves to determine the optimum tempering conditions is explained.—B. G. B.

## MACHINING AND MACHINABILITY

**New Methods for Shaping Difficult-to-Machine Materials.** P. O'Keefe. (*Mat. Methods*, 1952, **36**, Oct., 121–123). New techniques recently developed to supplement conventional machining include electrolytic, electro-sparking, electro-arcing, and ultrasonic processes. Brief details of the mechanism of each method are given.—P. M. C.

**Hardening of Tools and Machining Metals by Means of the Electric Spark Method.** F. Vodička. (*Strojírenství*, 1952, **2**, 11, 526). [In Czech]. The author discusses the advantages obtained by the use of electric spark hardening of tools in the Mladá Boleslav Car Works. Removal of broken drills from drill holes in metal parts is easily achieved by the spark-method without damage to the component.—P. F.

**The Sharpening of Carbide Tools by the Spark Method.** W. N. Ulitin. (*Machine Moderne*, Sept., 1952: *Usine Nouvelle*, 1952, Oct. 30, 51). The electrical circuit of the necessary equipment is described, and the types of disc electrode are mentioned. The optimum conditions of electrode rotation, voltage, and current are given. Advantages over the use of abrasive grinding are explained.—T. E. D.

## CLEANING AND PICKLING

**Abrasive Finishing.** R. H. Warring. (*Product Finishing*, 1952, **5**, Sept., 38–43). An outline of the processes in barrel finishing, rumbling, and tumbling is given for the non-technical reader.—J. P.

**Abrasive Tumbling Offers Finishing Economies.** A. G. Gray. (*Products Finishing*, 1952, **17**, Nov., 66–68; *Metal Progress* 1952, **62**, Oct., 104–108). Operational procedures for, and advantages gained from using barrel finishing at a number of American plants are discussed.—J. P.

**Barrel Finishing.** (*Product Finishing*, 1952, **5**, Dec., 64–72). An example, in the form of a case history, of how this type of finishing procedure is being increasingly employed in Great Britain is given.—J. P.

**Vacu-Blasting** (*Welding and Metal Fab.*, 1952, **20**, Oct., 361–362). A new method for the cleaning of plates in preparation for welding is described. The unit consists of a blast gun, pressure blast generator, abrasive reclaimer, dust collector, and vacuum pump and motor. The abrasive is driven against the work surface under air pressure. An air stream through a vacuum return system picks up all abrasive scale, débris and dust, and these are carried to the abrasive reclaimer.—U. E.

**Backstand Grinding and Polishing.** J. Rhodes. (*Product Finishing*, 1952, **5**, Sept., 48–55). The principles, advantages, and applications of abrasive belt grinding and polishing are discussed. Modern equipment is described and illustrated.

**Complex Stainless Parts Resist Corrosion When Electropolished.** G. L. Shriver. (*Western Metals*, 1952, **10**, June, 51, 52). A brief outline is given of the plant and procedure necessary for electropolishing a variety of components. The chemically pure surface resulting from such polishing is given as the reason for greatly improved corrosion resistance of certain stainless steels.—P. M. C.

**On Electrolytic Polishing by Means of an Alternating Current. Influence of Carbon Content in Steels.** N. Takamoto and Y. Tanabe. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, Mar., 151–153). [In Japanese]. Results are quoted for 12 steel specimens. Current density and voltage decrease slightly in the carbon range of 0·1–0·75%, and fall considerably at the eutectoid composition. Bright surfaces can be obtained with $<1{\cdot}2\%$ C, but, above this figure, uniform surfaces are not obtained, and some electrical etching occurs.—K. E. J.

**On the Electrolytic Polishing of Mild Steel by Alternating Current.** A. Tanaka. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, Feb., 121–124). [In Japanese]. Experiments were made at 100 V., 50 cycles, using mixed phosphoric-sulphuric acid electrolytes. Polishing is only possible below 60° C., and best results are obtained at 45° C., at a c.d. of 200 amp./dm. There is little difference in the surface appearances using either A.C. or D.C. A.C. polishing produces greater loss in

weight, but projecting portions of the surface are more rapidly attacked with D.C.—K. E. J.

## PROTECTIVE COATINGS

**Review of Recent Developments in Electroplating.** H. Silman. (*Metallurgia*, 1952, **46**, Dec., 283–288, 298). A number of substitutes for nickel as an undercoat for chromium have been developed and details of their application and performance are given. The use of a periodic reversal in the current during plating reduces the tendency for nodules to form. A self-regulating high-speed chromium plating bath, using a sparingly soluble silicon fluoride catalyst has been developed. Plastic linings and coatings are being increasingly used in the plating industry.—B. G. B.

**Setting Up a Generator for Plating Purposes.** (*Indust. Finishing*, 1952, **5**, Nov., 268–270). Some practical hints are given for ensuring the best results from a newly installed motor generator set.—J. P.

**Surface Tension Control in the Plating Room.** J. B. Kushner. (*Products Finishing*, 1952, **16**, Sept., 32–36). Drag-out losses can be reduced considerably if surface active agents are added to processing baths. The content thereof and its effectiveness can be measured and controlled by a simple device called the Sur-Ten Meter.—J. P.

**Nothing Barred.** B. Collins. (*Product Finishing*, 1952, **5**, Dec., 78–82, 90). Procedures at the works of Electroplaters Ltd., Carntyne, Glasgow, are briefly described. The firm carries out metal spraying, polishing, plating, phosphatizing, galvanizing, tinning, and painting.—J. P.

**Triangular Logarithmic Net for Calculation of Plating Thicknesses.** D. R. Curry. (*Electroplating*, 1952, **5**, Dec., 397–399). A nomogram is presented for facilitating the calculation of thickness from measurements of weight loss and area.—J. P.

**Quantitative Measurement of Adhesion of Electrodeposited Metals.** H. C. Schlaupitz and W. D. Robertson. (*Plating*, 1952, **39**, July, 750–753, 764 ; Aug., 862–864, 932). A modification of the Brenner nodule method is proposed. In this, a thin foil of base metal is plated on both sides and nickel nodules electroformed on each face. These are gripped in a tensile testing machine and pulled to fracture.—J. P.

**Electrolytic Processes in Chemical and Metallurgical Industry—Principles of Electrolytic Processes.** H. J. T. Ellingham. (*Chem. Ind.*, 1952, Nov. 17, 1115–1118). In its simplest form, electrolysis consists of the transfer of an electron from one substance to another and each such transfer requires a fixed amount of electrical energy dependent only on the end-products of the reaction, which is therefore susceptible of direct calculation or measurement. Deposition from an aqueous or similar solution has a limited application owing to the associated chemical side-reactions, but the majority of cations and many anions can be separated electrolytically from molten salt solutions, and commercial production by this method is well established.—J. O. L.

**Protective Creams in the Finishing Shop.** E. E. Halls. (*Products Finishing*, 1952, **5**, Sept. 56–59). The properties and use of anti-dermatitis barrier creams are discussed.

**Metallic Coatings.** M. L. Hughes. (*Proc. Ebbw Vale Met. Soc.*, 1952, **2**, 50–64). The author reviews methods of applying metallic coatings to metals. Those mentioned are hot dipping, spraying, electro-deposition, solid diffusion, cladding, vapour-phase processes (*e.g.*, chromizing), salt replacement, sputtering, and evaporation *in vacuo*. A more detailed examination of the protective coatings of tin and zinc follows.

**A. W. Hothersall—An Appreciation of His Contribution to Electrodeposition.** G. E. Gardam. (*Bull. Inst. Met. Finish*, 1952/53, **2**, 4, 62–79). The author, the first Hothersall Memorial Lecturer and Medallist, outlines the progress of electrodeposition at Woolwich, giving a full bibliography of this work.—T. E. D.

**Heat Transfer in Liquid Bath Furnaces.** M. H. Mawhinney. (*Indust Heating*, 1952, **19**, Oct., 1788–1800, 1872–1876). Studies of the overall heat transmission in fifteen different liquid-bath furnaces for plating have been made, and the author discusses the practical applications of the results.

**Electroplating Steel Springs.** (*Product Finishing*, 1952, **5**, Sept., 85–87; *Electroplating*, 1952, **5**, Oct., 341, 331). *See J. Iron Steel Inst.*, 1953, **173**, Mar., 310.

**A New Method for the Measurement of the Thickness of Thin Coatings by X-ray Back Reflection Pictures.** F. Regler. (*Metallwirtschaft*, 1944, **23**, Aug. 20, 284–286). A new method is described by which it is possible to measure the thickness of a thin coating utilizing intensity measurements on two X-ray diffraction lines from the material beneath the coating. The principles of the cone back-reflection camera and Regler's focusing camera are described. Ionization chambers were also used for measurements of intensity.—R. J. W.

**Chromium Plating Pays Off for Steel Mills.** (*Steel*, 1952, **131**, Nov. 24, 108–112). Many parts of steelmaking equipment have been chromium plated, to give increased resistance to wear, abrasion and corrosion. Longer life and less maintenance have resulted. Coatings are usually applied directly to the steel surface in thicknesses over 0·001 in. Pieces up to 45 tons have been plated. Hydraulic equipment benefits particularly, also crane axle bearings. A high-speed chromium plating process has been developed.—D. L. C. P.

**Automatic Control Purifies Plating Wastes.** (*Canad. Metals*, 1952, **15**, Aug., 18–20). This article describes the control instrumentation used for the measurement and precipitation of chromium salts from electroplating waste solutions. The salts must first be reduced by the addition of ferrous sulphate and sulphuric acid to form the trivalent chromium salts, which are then precipitated at a *p*H of 7 with lime treatment. Control of the additions is made by electronically operated throttles, which depend upon the solution's *p*H value and oxidation-reduction potential. Higher efficiency and economies are claimed.—J. C. B.

**Hard Chrome Plating on Aircraft Parts.** G. C. Close. (*Products Finishing*, 1952, **17**, Nov., 32–40). The precautions taken to ensure satisfactory deposits of wear-resistant chromium are briefly described and illustrated.—J. P.

**Hard Chrome Surfacing for Crankshafts.** R. A. Love. (Diesel Power : *Australasian Eng.*, 1952, July 7, 67). A brief account is given of the various stages in the renovation of a worn crankshaft, as carried out by Koepsel and Love, Salt Lake City, Utah. The process involves cleaning, examination for cracks, pre-grinding, hard chromium plating, final grinding, heat-treating and micro-finishing.—P. M. C.

**Path to Enameling Shop Rough on Base Metals.** (*Steel*, 1952, **131**, Nov. 10, 104–106). This article gives advice on ensuring that the base metal for enamelling shops is kept in the best condition possible.—D. L. C. P.

**Silica-Free Enamels.** B. K. Niklewski and R. H. Ashby. (Inst. Vitreous Enamellers : *Sheet Metal Ind.*, 1952, **29**, Nov., 1037, 1038, 1040 ; *Foundry Trade J.*, 1953, **94**, Jan. 1, 21–23). The necessity for enamels maturing at low temperatures, particularly for aluminium, has led to the study of silica-free compositions. The authors have examined the composition $Na_2O$ 18%, $TiO_2$ 8%, ($P_2O_5$ + $Al_2O_3$ + $B_2O_3$) 74% ; the last three components being varied in a triaxial diagram whilst the other two components were kept constant. Fifty compositions were studied, and enamels of good workability, high reflectance and acid resistance were developed.—P. M. C.

**Ceramic Coating Saves Scarce Metals and Lengthens Life of High Temperature Parts.** H. Penton. (*Western Metals*, 1952, **10**, Apr., 37–39). The use of a newly developed ceramic coating, A-418–Ryanco–C, is described, and the excellent test results obtained on exhaust headers on Pratt and Whitney aero engines are outlined. Steels with less alloy content may be used for high temperature applications of this nature, and the ceramic coating was found to give very prolonged service life.—P. M. C.

**Production Methods in the Enamelling Shop.** (*Foundry Trade J.*, 1952, **93**, Nov. 6, 545–547). The compositions of facing sand, cast metal and alkaline cleaner are described, as used by one company. The casting is prepared by shot-blast, using No. 16 grade angular steel grit, with 20% silica-free grit for cleaning. The importance of slow milling of frits is mentioned. The author details the types of guns for enamel application, and also the muffle furnaces used for fusing.—E. T. L.

**Gas-Appliance Manufacture and the Enamelling Industry.** H. Hartley. (*Foundry Trade J.*, 1952, **93**, Dec. 4, 657–660). The history of gas-cooker manufacture is traced, and research divided into fundamental, applied, and process research on the art of enamelling.—E. T. L.

**Measurement of Adherence of Enamel to Sheet Iron.** M. Morren. (*Silicates Indust.*, 1952, **17**, Nov., 346–347). Equipment and its use for the measurement of the force necessary to separate the enamel from sheet iron is described. The results obtained also give the tensile strength of the enamel.

**The Source of Defect-Producing Hydrogen in Porcelain—Enamelled Steel.** (*Sheet Metal Ind.*, 1952, **29,** Dec., 1126–1127). The U.S. National Bureau of Standards recently investigated sources of defect-producing hydrogen in porcelain-enamelled steel by introducing heavy hydrogen (deuterium) as a tracer at different points in the coating process. It was shown that dissolved water in the frit was by far the most important source.—P. M. C.

**Spray Painting Techniques.** (*Product Finishing*, 1952, **5,** Oct., 40–47). Methods of using and maintaining spray guns are described.—J. P.

**Dip Painting and Spray Coating.** M. Reeves. (*Metal Ind.*, 1952, **81,** Nov. 21, 404, 405). This is a general description of paint application to metal surfaces, with particular emphasis on spraying techniques.

**Electrostatic Finishing.** A. L. Phillips. (*Indust. Finishing*, 1952, **5,** Nov., 272–274). Two methods of paint and varnish spraying are described. In the first, the finish is sprayed between the wires of a grid maintained at a high potential with respect to the grounded work. In the second, the spray pistol itself forms the high potential electrode.

**A Sound Painting Program Can Slash Maintenance Costs.** K. Tator. (*Chem. Eng.*, 1952, **59,** Dec., 144–146). Potential savings of 20–50% of current maintenance painting costs are possible on most chemical plants. The selection of paints and methods of achieving these savings are discussed.—T. E. D.

**Protective Painting of Metal Structures and Works of Art.** M. Fonteyn. (*Ossature Métallique*, 1952, **17,** Nov., 543–548). The influence of exterior conditions on adherence, drying, and durability of coatings is considered, and the influence of the orientation of painted surfaces with respect to sunlight and rain, the thickness of the coating, electrical couples, moisture in the pigment and other factors on the efficiency of protection are discussed.—P. F.

## POWDER METALLURGY

**The Production of Sintered Parts by the Die-Pressing Process.** K. Marquardt. (*Metallwirtschaft*, 1944, **23,** Oct. 20, 377–379). The fundamentals of the sintering process are described and the porosity, strength, and sliding properties of sintered parts made from metallic and non-metallic alloys are discussed.

**Extrusion Pressing in Powder Metallurgy.** R. Kieffer and W. Hotop. (*Metallwirtschaft*, 1944, **23,** Oct. 20, 379–386). The historical development of the extrusion press is described. The method of manufacture and the properties (including the density, hardness, strength, elasticity, conductivity and metallographic texture) of extruded sintered metals, including iron, are discussed.—R. J. W.

**Determination of the Pore Size Distribution in Porous Metal Bodies.** P. R. Marshall. (*Nature*, 1952, **170,** Nov. 1, 761). Low surface tension liquids give an inconveniently large capillary rise. Increasing gravity by a centrifuge method, followed by freezing the water in the pores with liquid oxygen and weighing, enables pore sizes in the range 7–250$\mu$ to be determined. Molten acetanilide (m.p. 114° C.) may replace water.—A. G.

**On the Magnetic Properties of Sintered Iron.** T. Okamura, H. Kojima, and Y. Kamata. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1951, **3,** Dec., 748–754). [In English]. The authors have developed a method for producing iron powder briquettes from $Fe(CO)_5$. The magnetic properties of the briquettes are superior to those of briquettes produced by any other industrial method.—J. T. W.

**How Powder Metallurgy Is Progressing.** H. W. Greenwood. (*Metallurgia*, 1952, **46,** Dec., 289–292, 298). The author discusses some of the recent developments in powder metallurgy and describes work carried out on metal powders, pressing and sintering, bearings, high temperature alloys and magnetic materials.—B. G. B.

**Cermets.** M. Kantzer. (*Métaux-Corrosion-Indust.*, 1952, **27,** Dec., 506–510). The preparation, properties, and uses of alloys of metals and ceramic materials, which are known as cermets, are discussed.—B. G. B.

**New Development of Sintered Materials for Machinery Parts.** E. Eisenkolb. (*Technik*, 1952, **7,** June, 311–318). The author describes, among other things, the manufacture of sintered sheet (the compacting of the sheet being done by rolling), impregnation of sintered iron with copper and its alloys for bearing surfaces, and the use of sintered parts to induce 'sweat-cooling' by the evaporation of a liquid as it reaches the surface from the porous interior, *i.e.*., the self-cooling of parts operating in hot conditions.—J. G. W.

**Mass-Produced Parts Made of Sintered Iron and Steel.** W. Schroeder. (*Technik*, 1952, **7,** June, 304–310). This is a survey of iron powder metallurgy covering manufacture of iron powder, compacting and sintering, and properties of sintered products, notably of porous bearings.—J. G. W.

**Special Position of Powder Metallurgy in the Manufacture of Permanent Magnets.** W. Hotop. (*Metall*, 1953, **7,** Jan., 1–9). The application of powder metallurgy to the manufacture of Alnico permanent magnets is described.—J. G. W.

**Surface Activity and Sintering Behaviour of Fine Grained Powders.** J. Hinnüber and O. Rüdiger. (*Arch. Eisenhüttenwesen*, 1952, **23,** Nov.–Dec., 475–482), The surface activity of metal powders can be measured by electron microscopic, X-ray, electron emission, oxidation, catalytic and gas evolution methods. The behaviour during sintering and the properties of the resulting products are dependent on the surface condition of the initial powder. The results of investigations on four tungsten powders are described; electron microscopy was the most successful method.—J. P.

**The Contraction of Powders of Non-Plastic Metallic Materials.** W. Dawihl. (*Arch. Eisenhüttenwesen*, 1952, **23,** Nov.–Dec., 483–488). The current theories of the mechanism of contraction of non-plastic powders (carbides, titania, alumina) on sintering are presented. The presence of lower-melting-point metallic binders may markedly accelerate contraction even below any melting or eutectic temperature. The binder is probably a plastic material forming a thin layer between the grains of the non-plastic constituent. If the adhesion between the two components is comparable with the surface tension of the plastic material, the latter, in shrinking, carried the non-plastic component with it. If the adhesion beween the components is much less than the surface tension, the binder spheroidizes in the interstices and the non-plastic constituent forms its own skeleton and there is no shrinkage.—J. P.

**Electric High-Temperature Furnaces with Molybdenum Elements.** R. Kieffer and B. Natter. (*Radex Rundschau*, 1948, No. 3–4, June, 49–56). A detailed survey is made of construction, properties, and control of various types of high-temperature furnaces using molybdenum resistance heating elements. These furnaces are used mainly for reducing metal oxides for powder metallurgy processes.—E. C.

## PROPERTIES AND TESTS

**Contribution to the Study of the Criteria of Strength of Metallic Materials.** L. Baes. (*Ossature Métallique*, 1952, **17,** Dec., 602–616). An exposition of the theory of the strength of materials as proposed by H. Schnadt is given using the method of Mohr's circles. The effect of various heat-treatments on the strength of chain links is shown and interpreted by the theory.—P. F.

**On the Change of the Modulus of Rigidity in Metals Caused by Cold Drawing and Annealing.** H. Yamamoto and H. Takei. (*Nippon Kinzoku Gakkai-Si*, 1952, **16,** Mar., 128–132). [In Japanese]. The effects of cold drawing and annealing (at various temperatures and times) on the modulus of rigidity of α-brass and mild steel wires were determined: electrical resistance was also measured. For mild steel, the changes in rigidity with cold drawing are more complex than for brass: the modulus of rigidity of the drawn wire is improved by a short annealing treatment at 300–500° C.—K. E. J.

**On the Rigidity Modulus and Its Temperature Coefficient of the Alloys of Cobalt Iron and Chromium.** H. Masumoto and H. Saitô. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1952, **4,** June, 246–254). [In English]. The rigidity modulus at 20° C., and its temperature coefficient in the range 20–50° C., were determined for a range of Co–Fe–Cr alloys containing 50–90% Co and $<20\%$ Cr, using a torsion pendulum. Max. and min. values of the modulus were found. The coefficient is negative for most alloys, but increases as composition approaches that of Invar (Co 54, Fe 36·5, Cr 9·5%).—K. E. J.

**Changes of the Modulus of Elasticity During Torsion.** N. N. Davidenkov, I. S. Zhakovskaya, and V. A. Zhuravlev. (*Zhurnal Tekhnicheskoi Fiziki*, 1950, **20,** 5, 534–542). The effect of cold working on the moduli of elasticity $E$ of low-carbon steel, brass, and duralumin was investigated. $E$ was determined by the resonance vibration method on a specimen suspended on two nodes. It was found that the progressive cold working (by torsion) was accompanied by a decrease in

*E*. Intermediate ageing restores *E* nearly to its original value. Tempering gradually restores the value of *E*. Residual stresses appear to be the main cause of the decrease in *E* during plastic torsion.—V. G.

**Local Deformations in Simple Tension and Their Rôle in Neck Formation.** P. Bastien, A. Popoff, and P. Azou. (*Rev. Mét.*, 1952, **49**, Nov., 783–790). The nature and distribution of deformations were investigated and the appearance of neck deformation studied for ferrite, copper, aluminium, and magnesium. In all cases necking occurred before the maximum stress was attained. The end of non-localized deformation seems to be governed by the form of the theoretical national tensile curve.—A. G.

**The Experimental Production of Small Tensile Specimens by Electrolytic Solution (Electro-Turning).** M. H. Farmer and G. H. Glaysher. (*J. Sci. Instruments*, 1953, **30**, Jan., 9–10). The problem of obtaining Chevenard tensile specimens, 1½ mm. in dia., without surface deformation, led to the production of the bars by electrolytic action. The electrolyte is applied as a stationary jet on to specimens rotating at 2000 r.p.m., moving to and fro along the axis at constant velocity. The composition of electrolytes, and working conditions are given. A highly polished specimen, essentially free from stresses, is obtained.—L. H.

**On the Thermal Expansion, Rigidity Modulus and Its Temperature Coefficient of the Alloys of Cobalt, Iron and Vanadium, and a New Alloy "Velinvar".** H. Masumoto, H. Saitô and T. Kobayashi. (*Sci. Rep. Res. Inst. Tôkohu Univ.*, A, 1952, **4**, June, 255–260). [In English]. Properties of Co–Fe–V alloys containing 50–80% Co and <13% V were examined, and Invar and Elinvar types were found. Addition of vanadium to Co–Fe alloys considerably reduces their expansion.

**Sub-Zero Strain Aging Affects Iron Properties.** (*Steel*, 1952, **131**, Sept. 1, 86–87). An investigation, by the American National Bureau of Standards, has shown that strain ageing has a pronounced effect on the true stress-strain relationship of ingot iron specimen extended in tension at temperatures as low as −120° C. The specimens were extended at selected temperatures ranging from −196° to +100° C. and after an interval of about 30 min. they were extended to fracture at a different temperature within the same range.—A. M. F.

**A Recording Stress Relaxometer.** J. R. McLoughlin. (*Rev. Sci. Instruments*, 1952, **23**, Sept., 459–462). The instrument described measures the lateral deflection of bowed steel strips in the load-measuring element. The deflection is measured electrically by means of a linear differential transformer coupled to a recording potentiometer through an A.C. electronic voltmeter.—R. A. R.

**Influence of Prolonged Storage on Cold Deformed Open-Hearth Mild Steel.** H. Jungbluth and E. Schmidtmann. (*Arch. Eisenhüttenwesen*, 1952, **23**, Nov.–Dec., 439–441). Some compression-test samples of open-hearth steel (0·09% C, 0·16% Si, 0·33% Mn) from experiments carried out 26 years ago have been re-examined. No significant recovery or reduced internal stress and cold work could be detected, even on samples which had been deformed up to 75%.—J. P.

**The Cause of the Natural Yield Point.** W. Engelhardt. (*Technik*, 1952, **7**, Sept., 515–517; Nov. 659–622). The author describes three theories for the yield point phenomenon : Hort's friction theory, the cementite network theory, and the Cottrell theory.—J. G. W.

**Tensile and Impact Properties of High-Purity Iron–Carbon and Iron–Carbon–Manganese Alloys of Low Carbon Content.** N. P. Allen, W. P. Rees, B. E. Hopkins, and H. R. Tipler. (*J. Iron Steel Inst.*, 1953, **174**, June, 108–120). [This issue].

**Radiographic Stress Measurements, on the Question of the Increase in the Bending Yield Point of Steel by Bending.** R. Glocker and E. Macherauch. (*Z. Metallkunde*, 1952, **43**, Sept., 313–316). The authors describe experiments to ascertain whether the yield point is higher in bending than in tension. Steel specimens of various cross sections were polished, annealed, and subjected to bending stresses under controlled conditions, the stresses being evaluated radiographically. When the load was applied uniformly to bars free from internal stresses, and when the amount of bending was small, there was no increase in yield point. Very small variations from these carefully controlled stresses, *e.g.*, by adding the load in stages instead of by a uniform increase, an increase in yield point of up to 12% was found.

**Plastic Flexure of Mild Steel Beams of Rectangular Cross-section.** K. K. Shackell and J. H. Welsh. (*Proc. Inst. Mech. Eng.*, 1952, **166**, 1, 112–119). Tension, compression, and flexure tests have been carried out on a 0·28% carbon steel to a maximum strain about three times that at the initial yield. The object of the tests was to investigate the shape of the stress–strain curve immediately after yielding, and to determine whether the upper yield stress can be relied upon as a criterion of design in cases of flexure. The results show a rapid although not immediate fall from the upper to the lower yield value, and indicate that a beam is capable of withstanding a slightly greater bending moment than would be predicted by calculations based on the direct stress tests, including the upper yield stress.—P. M. C.

**Testing Cables and Wire.** A. V. Leites. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 758). [In Russian]. The difficulties of preventing the method of securing wire or cable specimens in tensile tests from influencing the results are considered, and a new technique, in which the specimen is wound on drums is briefly described.—S. K.

**Mechanical Properties in Torsion and Poisson's Ratio for Certain Stainless Steel Alloys.** C. W. Muhlenbruch, V. N. Krivobok, and C. R. Mayne. (*Proc. Amer. Soc. Test. Mat.*, 1951, **51**, 832–856). Modulus of elasticity in shear, shearing yield strength, and Poisson's ratio have been studied for several stainless steels. The torque-twist relationships are non-linear, and so also are the tensile or compressive stress–strain diagrams. Values for secant shearing modulus of elasticity and a yield strength at a limiting amount of torsional strain are given as applicable to design problems. Work hardening reduces the shearing modulus and increases the shearing yield strength. Poisson's ratio for longitudinal specimens is almost constant with increasing stress up to, and in some cases beyond, the yield strength. The ratio increases with increasing stress for transverse specimens. Harder tempers have higher Poisson's ratio than softer tempers. Reasons for these fundamental behaviours are proposed. The usual value of Poisson's ratio of 0·30 may be satisfactory in some cases but is in considerable error in others. A theoretical relationship between Poisson's ratio and secant moduli in tension and shear is presented.—B. G. B.

**Hysteresis of Shaft Materials in Torsion.** W. P. Welch and B. Cametti. (*Trans. Amer. Soc. Mech. Eng.*, 1952, **74**, July, 753–764). Details are given of the apparatus used for, and of the results obtained from, a determination of the hysteresis values of typical shaft materials in torsion, using specimens of 0·95% Cr and 0·2% Mo steel, a 0·14% carbon steel, and two non-ferrous alloys.—D. H.

**Study of the Friction Factor in Plastic Compression.** L. D. Sokolov and N. A. Chelyshev. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 757–758). [In Russian]. In the investigation described, compression of plate specimens was carried out at the rate of 0·1 mm./sec. The specimens were compressed while resting on the plate of a hydraulic dynamometer, and the actual data obtained are compared with those calculated by various formulæ.—S. K.

**Comparative Impact Testing of Specimens of Square and Circular Cross-Section Weakened in Various Ways.** G. I. Pogodin-Alekseev. (*Zavodskaya Laboratoriya*, 1950, **16**, 6, 721–728). [In Russian]. Impact tests have been made on cylindrical and square specimens of boiler, structural, axle, spring, and tool steels, with and without notches. The square and cylindrical specimens with notches of the same profile gave coincident values for the brittle, transition, and ductile ranges, but the absolute toughness values differ.—S. K.

**Charpy Impact Test Specimen Notched by Impact.** R. Mitsche. (*Berg- hüttenmänn. Monatsh.*, 1952, **97**, Apr., 72–73). In order to test for notch brittleness produced by 'natural' notches, not produced by machining, such as may occur in welds or structures, a method is devised in which a specimen is first provided with a notch through the free impact of the pendulum of the impact machine, and then subject to an impact test. The effect of the deformation in the notched region on the impact strength is investigated by comparing the results so obtained with the impact strength, obtained under similar conditions, of a similar specimen containing a similar notch, which has, however, been machined and is not associated with a work-hardened region, or subject to triaxial stresses.—P. F.

**Notch Toughness of Four Alloy Steels at Low Temperatures.** W. B. Seens, W. L. Jensen, and O. O. Miller. (*Proc. Amer. Soc. Test. Mat.*, 1951, **51**, 918–930). The authors present data on the effect of temperature, from room temperature to

— 315° F., on notch toughness by the Charpy keyhole test of three low-alloy steels and one medium alloy steel intended for use at low temperatures. Steels containing nominally 2·5% Ni, 3·5% Ni, 3·5% Ni with 0·25% Mo, and 9% Ni were investigated. Charpy impact specimens with keyhole notch were taken from ½-in. and 2-in. thick plates and from tubing of the 3·5% and 9% Ni steels. For the plates, considerable differences in energy were found between longitudinal and transverse specimens, except at low temperatures where the energy absorbed was small. Little difference was found between specimens from two different locations in the plate. The tests showed that notch-toughness at low temperatures could be greatly improved by heat-treatment. The tubing retained a greater proportion of its toughness at low temperatures than the plate due both to the faster cooling rate associated with thinner material and to the less severe restraint in the test specimens.—B. G. B.

**Extension of the Simple Plastic Theory to take Account of the Strain-Hardening Range.** J. W. Roderick and J. Heyman. (*Inst. Mech. Eng. Advance Copy*, Jan. 15, 1952). The authors deal with the simply supported rectangular section beam, subjected to flexure by symmetrical two-point loading. An expression for moment of resistance of such a partially plastic section in which some strain hardening has occurred, and slope deflection equations for loading sufficient to produce strain hardening, are derived.—P. M. C.

**How to Use the Sachs Boring Process for the Determination of Residual Stresses in Rods and Tubes.** H. Bühler and W. Schreiber. (*Métaux–Corrosion–Indust.*, 1952, **27**, Oct., 414–419). A mathematical analysis of the three basic equations proposed by Sachs is made. The authors develop equations and give an example of the practical application of their method.—B. G. B.

**Rational Choice of Methods of Measuring Elongation.** K. Fink. (*Z.V.d.I.*, 1952, **94**, Nov. 11, 1037–1038). The following methods for the determination of extensions in structures are surveyed: Brittle lacquer, photo-elastic, extensometers, and strain gauges. (25 references).—J. G. W.

**Hypotheses about the Influence of Size and Shape in Repeated Dynamic Stressing.** A. Troost. (*Metall*, 1952, **6**, Dec., 756–761). The following hypotheses are explained and compared: The Petersen–Thum hypothesis of notch stress-concentrations; Oding's hypothesis of relaxation of stress concentrations by plastic deformation; and the stress-gradient hypothesis. It is concluded that all these are special cases of the hypothesis of restricted plastic deformation, and that Oding's agrees most closely with experimental evidence.

**Relationship between Impact Strength after Ageing and Chemical Composition of Rimming Steels.** H. Kornfeld. (*Arch. Eisenhüttenwesen*, 1952, 23, Sept.–Oct., 345–350). Investigations into the notched bar impact strength after ageing of open-hearth and basic-Bessemer mild steels have shown that there is a connection between this property and the chemical composition, degree of deformation, and notch diameter of the specimens. This takes the form, for normalized steels, $\overline{K}_r(u, v) = 100(1-\exp(-c/uv)$, where $\overline{K}_r$ is the relative mean impact strength, $u$ is a variable depending on the chemical composition (here called the 'impurity'), $v$ is the degree of deformation in percent, $c$ is a value related to the diameter ($d$) of the notch. When $d$ lies between 1 and 4 mm., $c(d) = l + m.\exp(-n/d)$ where $l$, $m$, and $n$ are constants. The impact strength after ageing is well represented by the above formula if the impurity is equated to the Stromeyer relationship, $(\%\,P - 5\cdot\%\,N_2) \times 10^3$.—J. P.

**The Nature of Cleavage Fracture in Steel.** H. M. Miekkoja. (*Welding J.*, 1952, **31**, Oct., 493s–501s). This is a review of work on the effect of transition temperature, crystal structure, and alloying elements on cleavage fracture in low-carbon steels. (31 references).—U. E.

**Shearing and Slip Do Not Exist.** R. Vallette. (*Génie Civil*, 1953, **130**, Jan. 15, 26–29). The subject of deformation in materials is reconsidered. Shearing, punching, and twisting are discussed. Vector diagrams representing forces in steel under certain conditions are given. It is concluded that shearing and slip are theoretical phenomena and do not exist physically.—T. E. D.

**Contribution on the Photoelastic Method of Measuring Strains Using the plastic Markon 7.** J. Aubaud. (*Recherche Aéronaut.*, 1952, Nov.–Dec., 51–58). A study is made of the behaviour of a commercial polyester resin, Markon 7, when used for studying strain patterns by means of birefringence.

**Electronic Metering.** A. Ducrocq. (*Usine Nouvelle*, 1952, **9**, Dec. 11, 25–29; Dec. 18, 23–25). The measurement of length using electronic metering is surveyed. The method of operation of strain gauges is discussed. The measurement of thickness using $\beta$-rays is mentioned and types of counters are described. Measuring pressure by the alteration in electrical capacity of a capsule is described, and the use of the oscillograph for interpreting cyclic changes of pressure is discussed.—T. E. D.

**The Measurement of Strain by Electronic Methods.** S. F. Smith. (*J. Soc. Eng.*, 1952, **43**, Oct.–Dec., 163–182). The method of construction and operation of resistance strain gauges, and the types of electronic measuring equipment are described. Difficulties in installation of gauges and errors encountered are discussed. Uses in measuring soil pressure, water pressure, static loads, and acceleration are mentioned.

**A Routine Method for the Measurement of Residual Stresses in Plates.** R. G. Boiten and W. Ten Cate. (*App. Sci. Res.*, 1952, **3A**, 5, 317–343). A modification of the 'drill-hole' method using resistance strain gauges is described. Theoretical aspects of the problem are fully discussed. The relations derived are compared with test results.—T. E. D.

**Practical Procedure and Special Applications of the Turning Method of Determining Residual Stresses.** H. Bühler and W. Schreiber. (*Metall*, 1952, **6**, Nov., 685–688). The authors describe a technique and calculations employed in the Heyn-Bauer method of determining residual stresses in cylindrical parts, which they commend for practical applications not calling for high precision. The authors' method consists of turning the parts down in small equal steps and measuring the change in length, preferably by means of E.R.S. gauges. The variation of residual stresses is determined by the method of least squares. Advice on affixing gauges in internal bores is given.—J. G. W.

**A Method of Measuring Post-Yield Strain.** F. J. Woodcock and K. R. Weiss. (*J. Roy. Aeronaut. Soc.*, 1953, **57**, Jan., 49–51). The use of a wire resistance strain gauge element for post-yield strain measurements is examined. Results of experiments with various elements are quoted, the most satisfactory being 44 S.W.G. Eureka (56% Cu, 44% Ni). Sensitivity of the method and the circuit necessary are mentioned.—T. E. D.

**Electronics in Strain Measurement.** D. L. Johnston and D. W. Hobbs. (*Instrument Practice*, 1953, **7**, Jan., 191–199). A survey is made of electronic methods of strain measurement, under the headings: (1) Methods of detecting strain: mechanical and photo-elastic methods, and wire strain and bonded wire gauges; and (2) electrical methods of measuring strain. A number of applications of electronics are described and illustrated.—L. H.

**The Exploration of Stresses by Photoelasticity.** H. T. Jessop. (*Eng. Insp.*, 1952, **16**, Autumn, 90–96). A brief account is given of the potentialities of photoelasticity in regard to engineering stress problems. The treatment is purely descriptive, and covers the two-dimensional and frozen stress techniques. Brief reference is made to the more recent scattered light method for three-dimensional analysis.

**On the Wavy Deformation of Contact Metal Surfaces.** M. Tanaka. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, Mar., 177–181). [In Japanese]. Surface conditions, compressive stresses, and roughnesses are reported from tests wherein surfaces of specimens of mild steel, axle steel, grey cast iron, copper, and brass were brought into contact with similar surfaces, and others of the group, under pressure.—K. E. J.

**The Nature, Origin and Effects of Residual Stresses.** R. G. Treuting. (*Amer. Soc. Met. Special Publ.* "*Residual Stress Measurements*", Oct. 15–19, 1951, 1–41). Residual stresses, resulting from localized changes in volume and shape of metals, may effect electrical, magnetic, chemical, physical or mechanical properties. Ranging from dislocations or lattice defects to gross distortions, the fundamental mechanism of stress effects is becoming more susceptible to measurement in terms of the state of strain, determined from mechanical or X-ray examination, and a knowledge of the elasticity relationship, thereby enabling behaviour to be forecast on a basis of structural characteristics.—J. O. L.

**The Measurement of Residual Stresses.** J. J. Lynch. (*Amer. Soc. Met. Special Publ.* "*Residual Stress Measurements*", Oct. 15–19, 1951, 42–96). Mechanical or X-ray measurement of strain permits calculation of the corresponding stress. This paper contains a comprehensive general

description and mathematical treatment of methods, discusses local strain techniques, diffraction and deflection methods and approximations.—J. O. L.

**Residual Stress States Produced in Metals by Various Processes.** H. B. Wishart. (*Amer. Soc. Met. Special Publ.* "*Residual Stress Measurements*", Oct. 15–19, 1951, 97–128). The magnitude and distribution of stresses induced by heat-treatment, mechanical working, carburizing and nitriding are considered and the modifying factors, such as size and composition, are discussed. Particular examples are cited from works experience, but the results cannot be used as a general guide to behaviour, even of similar materials.

**Relief and Redistribution of Residual Stresses in Metals.** D. G. Richards. (*Amer. Soc. Met. Special Publ.* "*Residual Stress Measurements*", Oct. 15–19, 1951, 129–204). Methods for the redistribution or relief of stress can be classified under three heads : thermal, mechanical, and chemical. Thermal and mechanical treatment may cause redistribution by plastic deformation or volume change, whereas chemical attack normally results in the removal of stressed metal or the release of strain. When the stresses are on a macro scale, however, treatment may so modify the properties of the material as to outweigh the benefit obtained by the more even distribution of stress, and consideration must be given to the operational duty of the final product in deciding on an appropriate relief cycle.—J. O. L.

**The Determination of the Energy Stored in a Metal during Plastic Deformation.** L. M. Clarebrough, M. E. Hargreaves, D. Michell, and G. W. West. (*Proc. Roy. Soc.*, 1952, **215A,** Dec. 22, 507–524). A new apparatus for measurement of stored energy utilizes differential heating *in vacuo* in a calorimeter furnace. Small amounts of some impurities apparently produce large differences in recrystallization temperature and the release of stored energy, while in other cases impurities may affect the total energy.—K. E. J.

**A Theoretical Examination of the Plastic Deformation of Crystals by Glide.** J. F. W. Bishop. (*Phil. Mag.*, 1953, **44,** Jan., 51–64). Proofs are given of theorems in the Bishop-Hill theory of crystal distortion. Mathematical relations are established for deformation by simultaneous shears, and the enforcement of an arbitrary strain by glide is examined. A geometrical picture of stress and strain states is developed. Uniform elongation of a face-centred cubic crystal is discussed.

**The Effect of Strain-Rate on Twinning and Brittle Fracture.** D. Rosenthal and C. C. Woolsey, jun. (*Welding J.*, 1952, **31,** Oct., 475s–492s). The relationship between strain rate, temperature, twinning, and brittle fracture was investigated experimentally in simple tension. It was found that at −170° F. twinning appears to be insensitive to the rate of deformation ; brittle fracture was practically insensitive to strain rate (from 0·02 to 275 ft./sec.) and an increase of only 25° F. in the transition temperature was found over this strain rate. (35 references).—U. E.

**Effect of Strain-Temperature History on the Flow and Fracture of Ingot Iron at Low Temperatures.** G. W. Geil and N. L. Carwile. (*J. Res. Nat. Bur. Stand.*, 1952, **48,** June, 399–406). The effect of the strain-temperature history of ingot iron on the true stress/strain relationship for tensile specimens extended at temperatures ranging from −196° to +100° C. is reported. Specimens of ingot iron in various initial conditions were extended to a specified strain at a selected temperature and subsequently extended to fracture at a different temperature. The deviation of the true stress/strain values for the second stage of these tests from corresponding values for a single stage test generally increases at a decreasing rate as the prestrain of the specimen increases.—J. C. B.

**Radiographic and Mechanical Deformation Measurements on Grey Cast Iron.** V. Hauk. (*Arch. Eisenhüttenwesen*, 1952, **23,** Sept.–Oct., 353–361). Mechanical and X-ray measurements of deformation and stress during tensile, compression and bending tests have been conducted on cast iron with medium-coarse graphite. The radiographically determined deformations were smaller than those measured mechanically. The tensile stresses calculated from X-ray results were smaller and the compressive stresses larger than those determined mechanically. Since the X-ray method measured only the elastic deformation of ferrite at the surface and the mechanical method the mean value over the whole cross section, the elastic component of the mixed elastic and plastic deformation, the differences between the deformation of the ferrite and the whole structure, and between the deformation at the surface and the mean value over the cross section, can be obtained by comparison of results from the two methods. This permits a representation of the deformation mechanism of cast iron. The structure of the material may be represented as a series of thick-walled cells.—J. P.

**The Fatigue of Metals; Facts and Theories Reviewed.** B. R. Byrne. (*J. Soc. Eng.* 1952, **43,** Oct.–Dec., 183–203). The definition of fatigue and methods of testing are outlined. The S–N curve (stress amplitude–number of cycles) is examined and statistical aspects of fatigue measurements are discussed. Certain design features for minimizing fatigue failures in service are illustrated.—T. E. D.

**High-Speed Machine for Fatigue Studies.** G. R. Gohn. (*Bell Lab. Record*, 1952, **30,** Dec., 459–463). This article describes a fatigue testing machine for flat-type contact springs as used in telephone apparatus. It can test sheet metal in the range 0·01–0·04 in. thick at 3000 cycles/sec., and deal with 24 specimens simultaneously.—J. C. B.

**Fatigue Machines for Low Temperatures and for Miniature Specimens.** W. N. Findley, P. G. Jones, W. I. Mitchell, and R. L. Sutherland. (*Amer. Soc. Test. Mat. Bull.*, 1952, Sept., 53–55). The design and features of the following new types of fatigue testing machine are described : (1) A high-speed rotating-beam fatigue machine designed for operation at temperatures as low as −320° F. ; (2) a repeated-bending fatigue machine for tests at temperatures as low as −320° F.; (3) a repeated-bending fatigue machine equipped with suitable fixtures to permit tests of miniature specimens $\frac{3}{4}$ in. long in either bending or torsion.—B. G. B.

**On the Statistical Interpretation of Fatigue Tests.** A. M. Freudenthal and E. J. Gumbel. (*Proc. Roy. Soc.*, 1953, **216A,** Feb. 10, 309–332). There is always considerable scatter in results of fatigue tests performed under 'identical' conditions, due to the influence of happenings on the microscopic scale. The statistical theory of extreme values can be applied to the observed frequencies of survival : methods are presented for computation of the parameters of the 'survivorship function'. (20 references).—K. E. J.

**Processes Occurring in a Metal Subjected to Tensile and Oscillating Stresses. IV.—Internal Notch Effect and Surface Sensitivity Under Bending Fatigue Stresses.** C. Petersen. (*Z. Metallkunde*, 1952, **43,** Dec., 429–433). Continuation of a series of articles (*see J. Iron Steel Inst.*, 1951, **169,** Dec., 416). All materials are in some degree heterogeneous, and the theoretical state of uniformly distributed stresses has, in practice, micro and submicro loads and residual stresses superimposed on it ; the peak of these stresses determines the danger of fracture : smaller stress peaks can be ignored. The author develops the 'equivalent notch theory' by imagining a specimen of a homogeneous material in which a single notch is cut at the position of the micro-stress peak, its dimensions giving it the equivalent stress-raising value. Using this, he derives quantitative data from a general theory of fatigue for steel and the internally notched materials cast steel, malleable cast iron, and grey iron. It is shown that the surface sensitivity to alternating stresses and the internal notch effect are similar phenomena, so that the former can also be calculated from the formula for the latter. In the case of a machined surface, the work-hardening must be taken into account.—R. A. R.

**Hypotheses Concerning the Magnitude and the Effect of Shape When Fatigue Testing.** A. Troost. (*Metall*, 1952, **6,** Nov., 665–674). This is a review of modern ideas on the effect of size and shape on fatigue strength, based on 45 references to theoretical and experimental work.—J. G. W.

**Friction, Frictional Oxidation, Fatigue Fracture of Metals.** W. Späth. (*Metall*, 1953, **7,** Jan., 34–36). The author reports on the researches of F. P. Bowden and his co-workers into solid friction, particularly concerning the appearance of hot spots, and collates them with investigations by Fink and Hofmann into fretting corrosion. He suggests that fatigue fracture is the outcome of local melting phenomena akin to Bowden's hot spots ; melting may heal cracks, but the high temperature may cause oxidation leading ultimately to failure.—J. G. W.

**Contribution to the Study of the Effect of Dimension in the Fatigue Testing of Metals—Statistical Results.** R. Cazaud. (*Met. Ital.*, 1952, **44,** Oct., 512–517). The author defines the significance of results of fatigue tests of metals subjected to alternate tensile-compression and rotating bending stresses,

while taking into consideration the size of the test specimens and the statistical scatter of the results. (12 references).

**Optical Dynamic Weighbar for a Fatigue Testing Machine.** P. G. Forrest. (*Engineering*, 1952, **174,** Dec. 19, 801). The author describes the design and fabrication of a weighbar which can be fitted permanently in a Haigh fatigue machine in series with the test piece, to give a direct measure of the load range during tests.—M. D. J. B.

**Fatigue Cracks in Bi-Cylindro-Conical Hoist Drums.** M. H. Thompson. (*J. S. African Inst. Mech. Eng.*, 1952, **2,** Oct., 61–88). This paper describes the cracking which occurred in a series of large winder drums constructed with 'flywheel type' ends. The author describes the investigations carried out to ascertain their cause and the methods adopted in making effective repairs.—J. C. B.

**Relation Between the Fatigue of Steels and Their Plastic Deformation.** A. Fotiadi. (*Métaux–Corrosion–Indust.*, 1952, **27,** Nov., 425–445). The author considers two types of steel, one quenched and reheated to give a mixed ferrite–austenite structure and the other where there is one single phase either ferrite or austenite. The reaction of these two different structures to fatigue and plastic deformation are discussed in detail. The behaviour of a number of different steels with respect to plastic deformation and fatigue is reviewed.

**Influence of Fatigue Phenomena on the Modulus of Elasticity of Steels.** A. Kovacs and P. Laurent. (*Compt. Rend.*, 1952, **235,** Nov. 10, 1103–1104). Previous work has suggested a variation in the modulus of elasticity during rotational or alternating bending tests. Results for a Ni–Cr constructional steel show that this variation is due to a progressive modification of stress distribution resulting from initial heterogeneity.

**Studies on the Fatigue of Steels by Means of the Magnetic Method. (2nd Report).** T. Ueda and M. Tanaka. (*Nippon Kinzoku Gakkai-Si*, 1952, **16,** June, 325–328). [In Japanese]. Differential hysteresis loops were determined for 0·8% carbon steel wires unstressed, and loaded in a vertical twisting machine after various heat-treatments. Substantial changes occurred in the loops only when the repeated stresses exceeded the fatigue limit. With heat-treated wires, the loops changed more evenly with increase of number of cycles than with cold-drawn wires : the loop area decreased in all cases.—K. E. J.

**Structural Changes during the Fatigue of Metals.** F. P. Bullen, A. K. Head, and W. A. Wood. (*Proc. Roy. Soc.*, 1953, A, **216,** Feb. 10, 332–343). X-ray diffraction and metallographic examinations have been made of a metal subjected to cyclic stresses. When a symmetrical cycle is built up slowly, widespread breakdown into disorientated elements occurs, but this is largely suppressed at fast rates. There is a delay period before the activation of the average slip movement. The mechanism of fatigue cracking is discussed. These phenomena are not observed under static stress, and are attributed to enhanced atomic mobility, giving a viscous type of flow. (15 references).—K. E. J.

**Interferometric Studies of Hardness Test Indentations : Investigations on Tungsten Carbide, Steel, Duraluminium and Tin.** S. Tolansky and D. G. Nickols. (*Phil. Mag.*, 1952, **43,** Apr., 410–421). Studies of the surface contours of test indentations by multiple-beam interference show that in polycrystalline masses there are only secondary differences in the patterns.—E. T. L.

**Hardness Measurement in the Ball Indentation Test with Pre-Load and Depth Measurement.** H. Kostron. (*Metall*, 1952, **6,** Nov., 688–692). A method is described for determining the characteristic constants of the work-hardening curve. The experimental procedure is that due to Alphor, who proposed measuring the depth of indentation in a ball indentation test. The author shows how the Class hardness number can be derived from these measurements. Corrections for the edge effect are proposed on the basis of the author's experiments.—J. G. W.

**Micro- and Macro-hardness.** H. Franssen. (*Metall*, 1952, **6,** Nov., 692–693). The author draws attention to the limitations of present-day microhardness testing machines and suggests that, to avoid false readings, the distinction between micro- and macro-hardness should not be made on the grounds of load. 'Microhardness' should be reserved for the hardness of constituent phases and 'macrohardness' for that of the aggregate.—J. G. W.

**The Indication of Directional Properties by Hardness Testing.** P. Grodzinski. (*Sheet Metal Ind.*, 1952, **29,** Oct., 908–914). A brief historical survey of the use of elongated indenters to show up directional properties in cold-worked materials is given. Modern methods, and the directional hardness of rolled copper and steel, are also briefly discussed. (15 references).—P. M. C.

**Influence of Mechanical and Electrolytic Polishing on the Micro and Macro Hardness of Metals.** T. Geiger. (*Sulzer Tech. Rev.*, 1952, No. 3, 17–23). The influence of the manner in which specimens are polished, their crystal orientation, and the method of testing is examined fully. Some experimental results from tests on austenitic Ni–Cr steel are quoted, and some conclusions are confirmed by X-ray diffraction and microscopic examinations.—T. E. D.

**Work-hardening of Annealed Mild Steel under Static and Dynamic Conditions.** A. W. Crook. (*Nature*, 1952, **170,** Dec. 27, 1124–1125). The variation of the index $n$ in the Meyer equation $F = kd^n$ has been studied under both static and dynamic conditions of loading. Results for mild steels indicate that under dynamic conditions less work hardening occurs, but this is temporary and the final state is identical with that after a static test.—A. G.

**A Theory of Work-Hardening of Metal Crystals.** N. F. Mott. (*Phil. Mag.*, 1952, **43,** Nov., 1151–1178). Two types of hardening are distinguished : Rapid, in cubic metals, and slower, in hexagonal crystals and cubic metals under easy glide conditions. A quantitative theory of rapid hardening is given ; this includes discussion of retention of dislocations in slip planes, grouping at the ends of slip-bands, hardening strains, sessile dislocations opposing slip, and the dynamic formation of slip lines and clustering of slip lines. Quantitative agreement is shown with observations on retained energy in cold-worked metal.—K. E. J.

**The Mechanism of Work Hardening of Metals.** N. F. Mott. (*Inst. Mech. Eng.*, Advance Copy, Nov. 14, 1952 ; *Engineer*, 1952, **194,** Nov. 21, 694–697). The author presents a model of what happens when a metal work-hardens. The theory is based on the acceptance of vacant lattice sites and dislocations in crystals. These are described, and the mechanism of plastic deformation by the formation of slip bands is outlined. Work-hardening is ascribed to internal strains around dislocations. Finally, thermal softening is discussed with reference to the formation and diffusion of vacant lattice sites in cold-worked material. (35 references).—P. M. C.

**Thermoelectric Power—Accurate Measuring Methods and Applications to the Study of the Heterogeneity of Alloy Structures.** F. Aubertin and C. Crussard. (*Met. Ital.*, 1952, **44,** Nov., 458–559). [In French]. The authors studied the variations of thermoelectric power in metal, with the changing of metal structure, and developed a method of carrying out accurate measurements. The method is applied to the study of aluminium alloys and steel. The results show that the formation of segregations of free atoms produces an important variation in the positive or negative thermoelectric power. This variation has also been observed during ageing and rapid dissolution of finely dispersed precipitates. Hardening is observed in the case of extremely dilute solutions, due to the formation of zones rich in free atoms.

**Some Problems on Quenched Steels. II. On the Mechanism of Temper Hardening in Quenched High-Speed Steel.** K. Monma. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1951, **3,** June, 330–340). [In English]. Secondary hardening in a quenched high-speed steel was studied by expansion, hardness and resistance measurements. Decrease in hardness by tempering at 100–350° C. is due to relief of internal stresses produced in quenching. Secondary hardening is due to precipitation of carbide from the residual austenite, the martensite transformation having very little influence.—K. E. J.

**The Mechanism of Rolling Friction.** D. Tabor. (*Phil. Mag.*, 1952, **43,** Oct., 1055–1059). The friction and surface damage have been studied when hard steel balls roll between flat parallel surfaces of a softer metal. On commencing rolling there is marked plastic flow, causing an increase of track width as the ball traverses it, accompanied by a reduction of rolling resistance. When the track reaches its maximum size the rolling is unaffected by boundary lubricants.—E. T. L.

**Abrasion Testing by means of "Disappearing" Markings.** P. Grodinski. (*Metalloberfläche*, 1952, **6,** Dec., A190–A192). The author first refers briefly to the method of measuring abrasion, by which an impression made by a diamond is measured before and after a grinding operation. The chief disadvantage of such an impression is the distortion of the edges. Two methods are described which are free from this objection.

**Metal Transfer and Wear.** I-Ming Feng. (*J. Appl. Phys.*, 1952, **23,** Sept., 1011–1019). The author's theory proposes that at points of contact, roughening of the surfaces occurs as a result of mechanical deformation under load. This roughening causes interlocking, and hence friction. A tangential force that separates the surfaces, leaves the interlocked material still united, parting off one of the constituents in the unwork-hardened material beneath ; this constitutes wear. Another cause of metal transfer is the diffusion taking place during the temperature flash on breaking contact. It is pointed out that the usual welding theory of friction ignores the importance of surface films.—E. T. L.

**On the Wearing of Carbo-Nitrided Steel (1st Report).** K. Ogawa. (*Nippon Kinzoku Gakkai-Si*, 1952, **16,** Feb., 86–91). [In Japanese]. Wearing tests for carbo-nitrided steels were performed after standardization of wearing pressure and velocity, and are reported in conjunction with steel hardness and internal stress. Wear resistance increases with hardness. To obtain good wear resistance, the retained austenite should be reduced to a minimum by selection of quenching or tempering temperatures. The mechanism of wear (including bright and ' fused ' wear) is discussed. (14 references).

**On the Wearing of Steel with Carbo-Nitriding (2nd Report).** K. Ogawa and E. Takeuchi. (*Nippon Kinzoku Gakkai-Si*, 1952, **16,** Feb., 92–95). [In Japanese]. Further wear tests were made on carbo-nitrided steel under standard pressure and velocity conditions. The effects of various solvents for surface pretreatment were examined. Initial and stationary (linear-rate) ranges of wear are distinguished : the life of the hardened layer can be estimated.—K. E. J.

**On the Wearing of Steel with Carbo-Nitriding (3rd Report).** K. Ogawa and E. Takeuchi. (*Nippon Kinzoku Gakkai-Si*, 1952, **16,** Mar., 147–151). [In Japanese]. Wear tests were performed, under standard conditions, on steels given varying carbo-nitriding treatments below the $A_1$ point : wear resistance was higher than for steels treated at higher temperature. The wear resistance is a function of a nitride layer enclosing cementite globules, the very thin but very hard layer, and low internal stress. Low temperature hardening is recommended for lightly loaded parts of complicated shape.—K. E. J.

**Intrinsic Magnetization in Alloys.** W. J. Carr, jun. (*Phys. Rev.*, 1952, **85,** Feb. 15, 590–594). The intrinsic magnetization of alloys among the iron transition group is explained using a Heitler-London model for the 3*d* electrons. The magnetic moment associated with each atom is determined by the principle of maximum spin, and the sign of the interaction between pairs from overlap of the wave functions. A large number of alloys derive their spontaneous magnetization from an antiparallel arrangement of atomic spins.—K. E. J.

**The Structure and Properties of Magnetic Alloys.** D. W. Davison. (Australian Inst. Metals : *Australasian Eng.*, 1952, Sept. 8, 44–49). Both of the main classes of ferromagnetic materials are discussed, namely, the ' hard ' alloys for permanent magnets and the ' soft ' alloys for coil cores. The review deals particularly with the atomic arrangements found in these alloys. Diagrams of the lattice geometry are included for most of the structures. Various magnetic properties are tabulated.—P. M. C.

**Development and Present Status of Permanent Magnet Materials.** W. Dannöhl. (*Stahl u. Eisen*, 1953, **73,** Jan. 15, 65–81). Permanent magnet materials have progressed through the stages : Martensitic steels, hardenable alloys ; alloys with a superstructure ; materials with preferred orientation obtained by recrystallization or by casting ; and sintered, pressed, oxide and powder magnets. A review is given of permanent magnet materials for special purposes and the influence of copper, titanium, sulphur and silicon additions to Fe–Al–Ni–Co alloys is discussed. Undeveloped possibilities and the usefulness of the newly derived theory of coercive force and demagnetization curves are indicated.—J. P.

**The Theory of the Coercive Field of Magnetic Materials.** S. Velayos Hermida. (Revista de Ciencia Aplicada, 1952, **6,** Sept.–Oct., 385–408). [In Spanish].

**New Measuring Yokes for the Magnetic Testing of Electrical Sheets.** W. Krug. (*Arch. Eisenhüttenwesen*, 1952, **23,** Nov.–Dec., 449–457). The requirements for the determination of magnetic properties of electrical steel sheets by the A.C. magnetization method are discussed, and two new yokes are described for testing strip samples and whole sheets.—J. P.

**A Method of Measuring the Magnetic Permeability of Rod Specimens.** H. Aspden. (*J. Sci. Instruments*, 1952, **29,** Nov., 371–374). A method was developed for the measurement of the permeability of open-ended rod specimens by detecting changes in flux density and field strength by means of a search coil and fluxmeter.—L. H.

**Low Carbon Steel with Special Magnetic Properties.** M. Markuszewicz and J. Groycki. (*Hutnik* (Katowice), 1952, **19,** 12, 423–428). [In Polish]. The influence of methods of steelmaking, plastic working and heat-treatment on the magnetic properties of low-carbon steel are outlined. Some indications as to the correct chemical composition of the charge and technology of production and heat-treatment of low-carbon steel bars and sheets of good magnetic properties are given.—V. G.

**On the Temperature Dependence of the Magnetostriction Constants in Iron.** T. Katayama. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1951, **3,** June, 341–355). [In English]. A formula for magnetostriction in iron single crystals was deduced by considering spin-orbit interactions among the electrons. The eigenfunction of the 3*d* zone was derived by the lattice function method. The energy of the spontaneously strained crystal was evaluated on the basis of irreducible groups of cubic symmetry. Numerical solutions gave reasonable agreement with experimental observations of the temperature variation of magnetostriction. (14 references).

**On the Effect of Heat-Treatment on the Magnetic Properties of Iron-Aluminium Alloys. I. Some Physical Properties in an Annealed State.** H. Masumoto and H. Saito. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1951, **3,** Oct., 523–534). [In English]. As aluminium content is increased, the density, intensity of magnetization, initial permeability and Young's modulus decrease regularly, and resistance increases almost linearly. Maximum permeability and magnetic residual induction increase initially and then decrease, while hysteresis loss and coercive force show the reverse changes. The existence of the structure $Fe_3Al$ produces a specific increase in density, and reduction in resistance and Young's modulus. (11 references).—K. E. J.

**On the Magnetic Shunt Characteristics of Fe–Ni–Cr Alloys and M.S. [Magnetic Shunt] Alloy.** H. Masumoto, Y. Shirakawa and T. Ohara. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1952, **4,** June, 237–245). [In English]. To improve magnetic shunt alloys, a study was made of the magnetic properties between −50° and 100° C. of Fe–Ni–Cr alloys containing 30–60% Ni and 1–18% Cr. Alloys with a magnetic transformation point at approx. 100° C. have good characteristics.

**The Effect of Annealing on the Magnetic Properties of Plastically Deformed Mild Steel. (3rd Report).** T. Kawasaki and G. Shinoda. (*Nippon Kinzoku Gakkai-Si*, 1952, **16,** June, 322–324). [In Japanese]. Recovery of hardness and magnetic properties by annealing were investigated for a plastically deformed soft steel (C 0·06–0·09%). An abnormal increase in strain sensitivity after annealing at 700° C. is attributed to low carbon content. The slope of the magnetization curve is decreased by plastic deformation, and restored by annealing.—K. E. J.

**The Effect of Temperature of Deformation on the Electrical Resistivity of Cold-Worked Metals and Alloys.** T. Broom. (*Proc. Phys. Soc.*, 1952, **65B,** Nov. 1, 871–881). Wires of various metals and alloys were drawn in a special apparatus at between −183° and 100° C., and their resistances were measured. Change of resistivity with deformation depends on the deformation temp. relative to recrystallization temp. Apparently anomalous resistivity increases for tungsten and molybdenum are explained qualitatively. A unified theory of the effect of deformation on resistivity can be based on stacking faults. (22 references).—K. E. J.

**Non-Destructive Testing.** A. Neth. (*Metall*, 1953, **7,** Jan., 31–33). This is a report on a conference at Leoken, which took place in October 1952. The discussion covered testing and equipment under the four headings : Gamma, beta, and X-rays ; ultrasonics ; magnetic and electric testing ; and surface and strain measurements.—J. G. W.

**X-Ray in Industry.** R. J. Wright. (Inst. Production Engineers : *Australasian Eng.*, 1952, Sept. 8, 68–71). This is a general survey of the production of X-rays, and their application to the testing of metal components in industry.

**X-Ray Protection Design.** H. O. Wyckoff and L. S. Taylor. (National Bureau of Standards Handbook 50, May 9, 1952). This 36-page booklet discusses recommendations for protection against X-rays and gives sample design problems and methods of computing barriers for real installations.—R. A. R.

**Gamma-Radiography.** H. Manley. (*Chem. Age*, 1952, **67,** Dec. 13, 795–796). A brief account is given of the uses of gamma-radiography in the inspection of manufactured articles. The cost of suitable isotopes, and some details of equipment, are also given.—T. E. D.

**Non-Destructive Testing: Standardization of Certain Methods in Germany.** O. Vaupel. (*Iron Steel*, 1952, **25,** Dec., 529–532, 534). Industrial radiography in Germany has been standardized to a large extent, both in dimensions of films and equipment, and in quality of the radiograph by means of 'wire penetrameters'. The author gives an account of this standardization, and describes the progress made in the standardization of magnetic testing.—G. F.

**The Present State of Non-Destructive Testing of Materials in Germany.** R. Berthold. (*Welding and Metal Fab.*, 1952, **20,** Mar., 111–112). The method of non-destructive testing of materials in Germany has been systematically developed since 1933. This is a review of its development up to the present time.—U. E.

**150-kV. X-Ray Equipment for the Radiography of Welds.** F. W. Waterton. (Inst. Electrical Engineers: *Engineering*, 1952, **174,** Dec. 12, 774–775). This paper describes a continuously evacuated X-ray apparatus constructed to radiograph circumferential welds in hollow fabricated drums or pipes, into the interior of which radioactive capsules could not be inserted.—M. D. J. B.

**Non-Destructive Testing—Quality with Fewer End-Product Failures.** S. A. Wenk. (*Steel*, 1952, **131,** Oct. 13, 158–163). The general principles and applications of non-destructive testing methods are discussed.—A. M. F.

**Rapid Testing Methods for the Detection of Confusion of Steel Types.** E. Baerlecken. (*Stahl u. Eisen*, 1953, **73,** Jan. 1, 30–34). Much trouble and danger can be caused by components being made, unintentionally, from the wrong types of steel. The danger may be eliminated if the products are checked before despatch. No method is completely satisfactory for this purpose; the advantages and disadvantages of chemical, electrochemical, spectrographic, and magnetic procedures are discussed.—J. P.

**Non-Destructive Crack-Testing Methods by Means of Radioactive Indicators.** K. Kaindl and A. Mathiaschitz. (*Werkstoffe u. Korrosion*, 1951, **2,** Oct., 368–369). In order to test finished articles without damage, for surface defects, alcoholic solutions of radioactive isotopes are absorbed into the metal by capillary action. Radiographs show corrosion effects such as destruction of grain boundaries, tension cracks and corrosion fatigue; the method is applicable to austenitic steels.

**Some Applications of Gamma-Radiography Techniques.** M. Falk. (*Atomics*, 1952, **3,** Oct., 249–255). The wide application of $\gamma$-radiography and the growing use of iridium$^{192}$ for thicknesses up to 1 in. of steel are mentioned. The recently introduced stereo-method is described with illustrations.

**Alternating-Field Electromagnetic Methods for Non-Destructive Testing of Ferrous Materials.** H. Goebbels. (*Arch. Eisenhüttenwesen*, 1952, **23,** Nov.–Dec., 443–447). By determining the change of impedance of an A.C.-fed coil, used to magnetize steel articles, it is possible to differentiate these with respect to composition, heat-treatment, and hardness. The suitability of welding electrodes can be assessed. The sensitivity of the instrument is influenced by the strength of the magnetizing current, the phase lag between current and voltage, and the frequency.—J. P.

**Experience with the Magnetic Induction Method of Crack Detection on Steel Bars.** H. Beuse and H. Koelzer. (*Arch. Eisenhüttenwesen*, 1952, **23,** Sept.–Oct., 363–367). Examination of bars with the magnetic induction method of Matthaes has shown that sensitivity is sufficient for detecting small cracks, of the order of 0·1 mm. deep, only when all external disturbing influences are eliminated. Routine testing by the magnetic induction method is more economic than other non-destructive procedures since magnetization of the bars is not necessary. With usual constructional steels, large non-continuous cracks are readily detected. Cracks of smaller depth are only partly detected, fine slag inclusions and hairline cracks are not indicated with certainty, and continuous cracks or inclusion stringers are not always shown.—J. P.

**Testing Spring Steels with the Förster Crack Detector.** K. Mathesius and H. Bentke. (*Stahl u. Eisen*, 1952, **72,** Dec. 4, 1587–1591). Tests have been carried out with the Förster magnetic induction crack detector on bars which had been given artificial defects before rolling. Slight elastic or plastic deformation and direction of magnetization could modify the image on the cathode-ray screen. The influence of the earth's field must be eliminated. The sensitivity for small crack depths and for defects in the body of the steel was low. The testing is made difficult by the fact that two processes, magnetizing and testing, are necessary, but careful operation will give a quantitative assessment of crack depths. The direction of the crack, normal or oblique to the surface, affects the indication. It is possible to test a whole length of a bar in a short time, and, in contrast to the magnetic powder method, the surface of the bar need not be clean.—J. P.

**Propagation and Detection of Fatigue Cracks.** R. Cazaud. (*Métaux–Corrosion–Indust.*, 1952, **27,** Dec., 475–485). The author first discusses the origin and development of fatigue cracks and then their direction and speed of formation. A number of processes for the detection of fatigue cracks are reviewed, including ultrasonic, magnetic, and fluorescent-oil methods. The results of some microscopic and X-ray diffraction examinations of fatigued specimens are also described.

**Ultrasonics in Wall Thickness Measurement.** A. E. Williams. (*Min. Mag.*, 1952, **87,** Dec., 329–334). Ultrasonic methods may be used for non-destructive testing of metal plate thickness; they are particularly useful for boilers, tanks, and pipes, which can be examined *in situ*. Accounts are given of the principles of resonance and pulse testing, and details are given of the Dawes thickness gauge, and the Hughes detector.—K. E. J.

**Measurement of the Thickness of Metal Plate by Ultrasonic Harmonic Method. III. On the Resonance of Lower Harmonic Order.** S. Tanaka and S. Yamada. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1951, **3,** June, 393–396). [In English]. When the harmonic order of the thickness resonance is very low, the calculated apparent velocity of sound tends to increase. A correction can be introduced by considering the phase shift due to the internal reflection of the waves.

**The Practical Use of Modern Techniques in Works Control.** L. Colombier. (*Bull. Cercle Études Mét.*, 1952, **6,** Sept., 83–88). A brief outline is given of the use of ultrasonics for the non-destructive testing of castings and forgings in particular. The use of magnetic sorting equipment for the rapid identification of types of scrap is also described.—T. E. D.

**Tests for the Identification of Alloys.** Steimetz. (Commission d'Ingénieurs: *Centre Doc. Sidér. Circ. Inform. Tech.*, 1952, No. 6, 844–850). The identification and marking of steel, during passage from the casting pit to the finished product, by a number of different methods, is described and discussed. The Brinell ball test, the magnetic susceptibility test and the method of identification by means of sparks produced on a grinding wheel are mentioned.—T. E. D.

**The Testing of Steel by the Spark Method.** Maillet and Couronne. (Commission d'Ingénieurs: *Centre Doc. Sidér. Circ. Inform. Tech.*, 1952, No. 6, 836–843) The identification of steel by the type of sparks which appear on a grinding wheel is outlined. A technique for photographing such sparks is described and a number of examples are given. The peripheral speed of the grinding wheel should be about 900 m./min. Among uses suggested is the rapid classification of scrap.—T. E. D.

**Black Light Spots Defects in Materials.** N. E. Walters. (*Mat. Methods*, 1952, **36,** Nov., 105–107). The Magnaglo and Zyglo methods of crack detection, using fluorescent particle suspensions and ultraviolet light, are described. The former is a magnetic method, the latter relies purely upon the penetrating ability of the particle carrier, and this can be applied to non-magnetic materials, glass, plastics, and ceramics.

**High Temperature Metallurgy: Jetomic Age Demands It.** B. P. Planner. (*Steel*, 1952, **131,** Nov. 3, 98–102). The properties of substances which may be of use in satisfying modern demands for materials that can withstand high temperatures under various conditions are considered. Metals and alloys, ceramic coated metals, ceramic bodies and cermets are reviewed.—D. L. C. P.

**The 475°C. Hardening Characteristics of Some High-Alloy Steels and Chromium Irons.** B. Cina and J. D. Lavender. (*J. Iron Steel Inst.*, 1953, **174,** June, 97–107). [This issue].

**New Alloy Tough in Hot Spots.** (*Steel*, 1952, **131,** Nov. 17, 90–91). The properties of a newly developed heat-resistant alloy, NA22H, are described. Analysis of a sample showed 0·44% C. 26·3% Cr, 46·0% Ni, 1·36% Mn, 0·99% Si, 5·28% W. Its creep, oxidation-resistance, weldability and

other characteristics allow it to give good service at over 2000° F.—D. L. C. P.

**Heat-Resisting Steels and Alloys for Gas Turbines; Their Development and Investigation in England.** E. Franke. (*Werkstoffe u. Korrosion*, 1951, **2**, Oct., 378–385). A survey is made of references, mainly in English technical literature, to the development and application of high-temperature steels for gas turbines.—L. H.

**The Ductility of Metals in Creep-Rupture Tests.** H. H. Bleakney. (*Canad. J. Techn.*, 1952, **30**, Dec., 340–351). The effects of impurities in commercially pure aluminium, copper, silver, lead, and iron are described. Brittle intercrystalline cracking in creep-rupture tests is discussed, and mechanisms are suggested for the observed phenomena.—T. E. D.

**Comparison of Relaxation Tests with Creep Tests.** W. Tomaszczyk and Z. Borysowski. (*Prace Inst. Metalurgii*, 1952, No. 4, 301–311). [In Polish]. The processes of relaxation and creep of Cr–Mo steel at 500° C. were compared, using the theories of ageing and strain hardening. It is concluded that the method cannot be generally applied for the determination of the relaxation of a given material from creep tests.

**Economic Pearlitic Steels for High Temperature Applications.** V. Malý. (*Strojírenství*, 1952, **2**, 11, 506–512). [In Czech]. The development of four new Czechoslovak low-alloy Cr–V and Cr–Mo–V steels for use in the range 400°–600° C. is described. Tensile strength and creep data are given.—P. F.

**Solving Problems in Materials.** T. S. Fuller. (*Amer. Soc. Test. Mat. Bull.*, 1952, Oct., 51–62). The author outlines the progress which the electrical industry has made during the last 50 years as a result of improvements in the materials used. New alloy steels have allowed an increase in the operating temperatures of steam turbines (and hence an increase in the efficiency), and ultrasonic testing is being used to ensure the soundness of materials in power-station equipment.

**A Survey of High-Temperature Materials.** J. M. Robertson. (*Metal Treatment and Drop Forg.*, 1952, **19**, June, 275–283; July, 303–312). The author first discusses creep, rupture and relaxation under static stress, high-temperature fatigue, effect of heating and cooling cycles, and reactions between metals and their environments. The types of alloys available for use in the range 450–950° C. are discussed with particular reference to precipitation-hardening treatments. The many types of alloy steel used in steam and gas turbine plants are tabulated and discussed in detail.—P. M. C.

**General Purpose High Temperature Alloys.** K. Rose. (*Mat. Methods*, 1952, **36**, Oct., 103–107). The author gives a general descriptive account of the properties and elevated temperature uses of nickel base alloys and of plain carbon, low-alloy, stainless, and high-alloy steels.—P. M. C.

**Steel Alloys for Sheet and Moulded Glass Manufacture.** A. Dammer. (*Werkstoffe u. Korrosion*, 1951, **2**, Nov., 409–414). For rolls and moulds in glass manufacture alloy steels must in general be used, as the properties required are strength at high temperatures, and resistance to attack by furnace gases and from the alkalis in the glass. High-nickel austenitic steels are customary. The properties required are discussed.

**Nitrogen Content and Low-Temperature Brittleness of Steel: Results of Study by U.S. Bureau of Standards.** M. Lorant. (*Brit. Steelmaker*, 1953, **19**, Jan., 18–19). A summary is given of the results of an investigation into the effects of nitrogen on the low-temperature brittleness of steels containing 0·3% C and 0·9–1·6% Mn, some being aluminium-treated. Increased nitrogen is shown to improve the low-temperature properties when present as aluminium nitride, but to be detrimental when present as the nitrides of iron and manganese.—G. F.

**Experiences with Boron Additions to Structural Alloy Steels.** H. Krainer and M. Kroneis. (*Stahl u. Eisen*, 1952, **72**, Dec. 18, 1652–1657). The influence of boron additions on hardenability and on mechanical properties has been investigated on Si–Mn and Mn–Cr–Mo–Ni steels. The hardenability curves of the former were displaced by boron additions to the upper boundary of the scatter band of the boron-free steel. In heat-treatment tests, an increase in tensile strength with reduced toughness was found with specimens 30 mm. in dia. but not with those 80 mm. in dia. The displacement of the end-quench curves corresponds to an increase of the manganese or chromium content of about 0·25%. Similar results were obtained with the other heat-treatable steels, but as a result of martensite formation the impact strength of the heat-treated boron steels was higher than that of the boron-free material. Boron is effective only if the hardening temperature is sufficiently high, but with the case-hardening steel no effect of boron could be detected.—J. P.

**New Titanium-Boron Alloy Steel Shows Promise for Jets and Rockets.** J. L. Everhart. (*Mat. Methods*, 1952, **36**, Sept., 96–98). Low-alloy steels such as a 3%-Cr 1%-Mo steel with titanium and boron, can serve satisfactorily for short life periods in applications where oxidation is not an important factor. The mechanical properties, heat-treatment, and welding characteristics of such a steel are discussed, and a comparison is made between the creep and rupture properties at 1200° F. with those of 18/8 Cr–Ni and 18/13/2 Cr–Ni–Mo stainless steels.—P. M. C.

**Electrolytic Manganese Acceptance Grows.** C. L. Mantell. (*Iron Age*, 1952, **170**, Sept. 18, 168–172). Electrolytic manganese supplied as a chip is finding favour as a substitute for nickel and has opened up a new field of manganese-based alloys. Its freedom from carbon and other elements is of special advantage in steel production. Iron–chromium–manganese steels show high resistance to corrosion and work-harden more rapidly than stainless steels. It is also suggested for making stainless steels of very low carbon content.

**Substitution for Strategic Metals in Steel Production.** S. L. Gertsman. (Canad. Inst. Min. Met.: *Canad. Metals*, 1952, **15**, Mar. 20–23; Apr., 24–25). Of the present shortages of nickel, molybdenum, tungsten, cobalt, columbium, and manganese, the manganese situation is the least critical. Low-alloy steel is discussed in the first part with emphasis on boron as a substitution element. The concluding part deals with stainless, heat-resistant, and tool steels.—J. C. B.

**Strategic Elements: Emphasis is on Conservation.** J. G. Terry. (*Steel*, 1952, **131**, Sept. 1, 82–84). A brief description is given of what the steel and allied industries are doing to conserve strategic raw materials. Nickel is being saved by using type 430 chromium stainless steel, and columbium can be eliminated as a stabilizer if the carbon content is kept below 0·03%.—A. M. F.

**Historical Aspects of and Conservation in Constructional Alloy Steels.** J. Mitchell. (*Metal Progress*, 1952, **62**, Oct., 97–103, 144). The author discusses the trends in the use of alloying elements in steel over the past 50 years, primarily with respect to nickel. In 1950 the average nickel content in constructional steels was 1·25% and by 1951 this was reduced to 0·90%, a reduction of 28%. Three methods of conservation have been responsible for this reduction. Since the average nickel content in the constructional steels has now fallen below 1%, the recovery of scrap is now only 43% as opposed to 63% in 1943.—B. G. B.

**Silicon Steels in the Electrical Engineering Industry.** R. Smith. (*J. Birmghm. Met. Soc.*, 1952, **32**, Sept., 103–116). The author deals with the historical development of silicon steels as they have concerned industry, followed by an account of the theoretical background to these developments. Preferred orientation and the associated magnetic anisotropy are discussed.—P. M. C.

**Special Steels in the Clock and Watch Making Industry.** (*Aciers Fins Spec. Franç.*, 1952, June, 64–66). The history of France's contribution to the watch and clock making industry is briefly reviewed. Details of special steels used in this industry today are also given.—E. C. S.

**Valve Steels.** (*Aciers Fins Spec. Franç.*, 1952, Mar., 60–63). The article deals with steels for both inlet and exhaust valves. The latter includes martensitic, austenitic, and steels hardening by precipitation.—E. C. S.

**The Use of Special Steels for Gears.** (*Aciers Fins Spec. Franç.*, 1952, Dec., 27–30). The article deals with the use of nickel, chromium, and molybdenum, in steels for gears. Case hardening, nitride hardening, flame hardening, and induction hardening are all briefly considered.—E. C. S.

**Manufacture of Bolts, Nuts and Screws of Stainless Steel.** (*Aciers Fins Spec. Franç.*, 1952, June, 79–81). The applications and properties of stainless steel bolts, nuts, and screws are discussed. Very little information on the manufacturing processes is given.—R. A. R.

**Modern Die Blocks.** (*Aciers Fins Spec. Franç.*, 1952, June, 88–90). Recommendations are made for steels for die blocks for the following purposes: (1) Producing small quantities; (2) mass production; (3) 'inserts'; and (4) dies for highly specialized work.—R. A. R.

**Tool Steels.** J. S. de Martinville. (*Bull. Cercle Études Mét.*, 1952, **6**, Sept., 89–95). A survey is made of the careful con-

trol which American tool-steel manufacturers employ. This covers close composition specifications, standardized production methods, carefully regulated heat-treatment, and rigorous final inspection .—T. E. D.

**Bigger Tool Steel Bars.** D. P. Hughes. (*Steel*, 1952, **131,** Nov. 3, 96–97). Bars of high-speed steel as large as 10 in. in dia., 10 ft. long and weighing over 2500 lb., are now being made without carbide segregation ; the implications of this are considered.—D. L. C. P.

**Machine Tool Materials.** W. D. Biggs. (*Welder*, 1952, **21,** 112, 91–94). After a brief outline of the properties required of any tool, the author classifies the materials available with data on room-temperature hardness, abrasion resistance, red hardness, distortion by heat treatment, hardenability, and toughness. Precautions and procedures to be adopted to obtain the best behaviour from the tools are suggested.

**Metallurgical Aspects of the Manufacture of Drilling Equipment.** (*Aciers Fins Spec. Franç.*, 1952, Dec., 70–74). The manufacture of oil-well drilling equipment other than seamless rolled tubes was not begun in France before 1941. The steels used for tool joints and drill collars, mud pump components, and transmission chains are considered.—E. C. S.

**Chromium Stainless Steels.** (*Sheet Metal Ind.*, 1952, **29,** Dec., 1089–1091, 1094). A report on a discussion recently held in Birmingham by the Stainless Steel Fabricators' Association. Questions and answers on problems associated with the industrial use of stainless steel are recorded.—P. M. C.

**Steel Wire Ropes.** A. E. Williams. (*New Zealand Eng.*, **7,** Oct., 360–363). Many typical examples of wire rope construction are described and their cross-sections illustrated. The importance of rope cores is emphasized, and the production of suitable rope wire of 100 tons per sq. in. tensile strength by cold drawing from carbon steel rod is described. The metallurgy of rope wire, particularly the requirements for elastic modulus, yield point, and fatigue limit are discussed.

**The Properties of Steel Wire.** W. E. Wagenknecht. (*Wire Prod.*, 1953, **2,** Jan., 4–8). The effect of an anneal at 700° and 1000° C., followed by a single heavy pass before patenting on high-carbon steel wire, were studied. Quadriplicate tension, torsion, and reverse bend tests on the drawn wire were made. The results showed that surface decarburization during the annealing made subsequent drawing difficult, but otherwise the effect of this treatment was far less noticeable than that of the patenting temperature (whether below or above $Ac_3$).—J. G. W.

**Evolution of Engineering and High-Strength Irons.** M. Ballay. (Fourth International Mech. Eng. Congress : *Foundry Trade J.*, 1953, **94,** Jan. 8, 41–45). Four types of grey irons are considered, namely, the unalloyed grey irons, alloyed cast irons, cast irons with spheroidal graphite, and corrosion-resisting and special-duty cast irons. The composition, mechanical properties and essential characteristics of each type are indicated. Suitable methods of heat-treatment are also given.—L. E. W.

**High-Duty Irons Reduce Costs.** C. E. Herington. (*Steel*, 1952, **131,** Sept. 15, 94–96). Examples are given of applications for Meehanite cast iron. These include rolls in a plate-bending machine, die sets for forming and stamping, high-duty castings for jigs and large nuts.—A. M. F.

**Sources and Identifying Symbols of Government Specifications.** S. F. Booth. (*Metal Progress*, 1952. **62,** Oct., 109–114). A list of the principal departments of the United States Government who issue specifications is given, together with the distinguishing symbols used by them.—B. G. B.

## METALLOGRAPHY

**New Microcinematographic Researches on the Deformation and Rupture of Steel.** G. A. Homès and J. Gouzou. (*Rev. Mét.*, 1952, **49,** Oct., 707–719). For mild steel under slow tension rupture is transcrystalline and begins at the centre of the specimen. A study of the cementite network in pearlite shows the possibility of translational slip in the (001) plane and [010] direction, and explains the observed flexion of pearlite lamellae. A thermal treatment to improve notch properties of steels is described.—A. G.

**Metallographic and X-Ray Examination of Mild Steel after Cold Deformation and Alternating Loading.** H.-R. Sander and M. Hempel. (*Arch. Eisenhüttenwesen*, 1952, **23,** Sept.–Oct., 383–405). The structure and change of crystal state of prestressed mild steel is described. The prestressing was carried out in tension at deformation rates of 0·005–0·015% and 20,000%/sec. With increasing degree of extension, static and dynamic deformation produced slip lines. In addition, mechanical twinning was observed at high deformation rates. After prestressing and subsequent alternating loading of a sufficiently high value and duration, globular cementite was precipitated on the slip lines, the amount increasing with degree of deformation in close relationship with the number of slip lines produced by the deformation. There is more precipitation in the surface zones than in the core of the material, showing that the surface suffers greater lattice distortion. A reversal of the deformation conditions or a cold deformation or alternating loading alone does not produce this precipitation.—J. P.

**A Low-Temperature X-Ray Powder Camera.** N. C. Tombs. (*J. Sci. Instruments*, 1952, **29,** Nov., 364). An adaptation of a Unicam 19 cm. circular powder camera is described, by which a cooling liquid, such as liquid air or nitrogen, is allowed to stream round a rod-type specimen during the exposure.—L. H.

**A Powder Camera Modification for High Temperature Photographs.** H. T. Heal, E. Gillam, and D. G. Cole. (*J. Sci. Instruments*, 1952, **29,** Nov., 380–381). The apparatus described was adapted from an ordinary camera, and used for powder photographs of thin steel strip, accurate temperature measurements not being required. The ribbon or wire is heated by a small current. The vacuum case, a brass cylinder, has a sellotape window, through which half of the customary symmetrical powder photograph is obtained. Photographs were taken at up to 1000° C., with exposures of up to 2 hr.

**Determination of Surface Geometry and Structure by Microscopy and Diffraction.** C. F. Tufts. (*Analy. Chem.*, 1952, **24,** Nov., 1700–1704). The author shows how light microscopy, electron microscopy, and electron diffraction can be used together to determine surface characteristics. The surface can be examined *in situ*, or the outermost layers can be removed from the bulk and examined as an isolated film.

**Adapting the Electron Microscope for Metallographic Examination of Steels.** A. Schrader and F. Wever. (*Arch. Eisenhüttenwesen*, 1952, **23,** Nov.–Dec., 489–495). The high efficiency of the electron microscope is illustrated by two examples of the metallography of steels which have not been solved with the optical microscope. It is shown that, in the pearlite transformation, the formation of cementite takes place first and that of ferrite afterwards. In the intermediate stage transformation, ferrite forms first ; carbide precipitation ensues from a carbon-enriched austenite which surrounds the ferrite needles as a fine envelope.—J. P.

**Microscopic Observation of Skin Structure of Finished Surfaces. On the Connection of the Measurement of Superfinished Surfaces.** A. Inoue and S. Mori. (*J. Mech. Lab.*, 1952, **6,** Sept., 175–178. [In Japanese]. The structure of superfinished surfaces of 0·1–0·9% C steels was examined by oblique sectioning. Various etchants were used and micrographs are shown.—J. G. W.

**Electron Microscopy of Solid Surfaces.** V. E. Cosslett. (*Nature*, 1952, **170,** Nov. 22, 861–863). Papers presented at a special session of a meeting of the Electron Microscopy Group of the Institute of Physics, September 16–19, 1952, are reviewed. The performance of 'reflection' electron microscopes of various types was discussed, a promising development being a scanning type which, owing to the absence of lenses, has a resolution limited only by the size of the exploring probe.—A. G.

**Electron Microscopy by Reflexion.** C. Fert and R. Saporte. (*Compt. Rend.*, 1952, **235,** Dec. 10, 1490–1492). Details of specimen preparation and of the electron microscope employed are given. Examples illustrating the effect of illuminating angle and observation angle are included ; with the latter at 4° the resolving power is approx. 250 Å.—A. G.

**A Revolving Specimen Stage for the Electron Microscope.** F. W. Bishop. (*Rev. Sci. Instruments*, 1952, **23,** Sept., 504–505). To allow orientation of the specimen by rotation, in addition to and independently of the usual stage movement controls, the stage was fitted with an auxiliary turntable, which was designed to take either the standard or stereo specimen holder. A new specimen door was designed to take a driving shaft to operate the turntable.—L. H.

**The Scanning Electron Microscope and the Electron-Optical Examination of Surfaces.** D. McMullan. (*Electronic Eng.*, 1953, **25,** Feb., 46–50). After a survey of the advantages and limitations of scanning electron microscopes, a new instrument

is described. This is a two-stage microscope with electrostatic lenses, and can be used for visual and recorded work, with opaque specimens. Constructional details and examples of its use are given, and the results are discussed.—L. H.

**Methods in Electron Microscopy of Solids.** R. D. Heidenreich. (*Rev. Sci. Instruments*, 1952, **23**, Nov., 583–594). The use of replicas in electron microscopy of metals is reviewed. Examples of plastic and oxide replicas are illustrated, with the technique of their preparation and evaluation. The use of electron diffraction patterns and the examination of thin metal sections by emission electron microscopy are described.

**Studies on the Microstructure of Steel at High Temperatures by Means of the Emission-Type Electron Microscope.** N. Sasaki, N. Kishimoto, R. Ueda, T. Koroda, and H. Okamoto. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, Mar., 165–169). [In Japanese]. Results of the examination of the austenite microstructure of various types of steel at high temperature, using barium and strontium as activators, are presented. It is suggested that simple heating of a polished steel specimen *in vacuo* or an inert gas might provide a substitute for the McQuaid-Ehn method of determining austenitic grain size. (20 references).—K. E. J.

**A Study on the Procedure of Grinding of Iron by Electron Diffraction Method.** S. Yoshioka and M. Mera. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, Feb., 95–100). [In Japanese]. Grinding was carried out (*a*) with fresh emery paper (short-grinding), and (*b*) with clogged cloths (long-grinding). With coarse emery, α-Fe reflections predominated, but with fine emery, rings of $Fe_3O_4$ and α-Fe were found. Long-grinding showed $Fe_3O_4$, although when grinding was intermittent, iron reflections appeared, suggesting a deoxidation effect. Results are analogous with those for copper polishing.—K. E. J.

**Electrolytic Slide-Polishing.** K. Nagai and K. Mano. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1951, 1–2B, Mar., 391–398). [In English]. Electrolytic slide-polishing, in which the cathode is placed below a textile or glass wool strip 0·5 mm. thick, and soaked in electrolyte, is described, its mechanism is explained and the results are compared with those obtained by conventional electropolishing. Larger voltage and current densities are required in the new method.—J. G. W.

**Autoradiography of Metal Surfaces Using a Radiochemical Method.** E. Rabinowicz. (*Nature*, 1952, **170**, Dec. 13, 1029–1030). The different chemical activities of various metals towards some radioactive substance, *e.g.*, iodine as amyl iodide, are utilized, the residual iodine layer producing an autoradiograph. Silver, chromium, lead, and copper react most strongly, brass, aluminium, tin, and mild steel producing thinner radioactive films.—A. G.

**Crystal Distortion of Graphite in Cast Irons.** E. Matuyama. (*Nature*, 1952, **170**, Dec. 27, 1123–1124). The variation of disordered structure within a graphite grain has been studied by removing successive layers with an oxidizing agent and obtaining Debye-Scheuer patterns. The crystal structure is most perfect in the core of the grains.—A. G.

**Carbide Segregation As Related to Tool and Die Life.** S. G. Fletcher and D. Hughes. (*Metal Treating*, 1952, **3**, Sept.–Oct., 6–8). The nature of carbide segregation is discussed, and its adverse effect on the toughness of high-alloy tool steels is shown by tests carried out by the authors. Further tests showed that carbide segregation has an adverse effect on distortion and machinability.—P. M. C.

**Carbide Segregation As Related to Tool and Die Life.** S. G. Fletcher and D. Hughes. (*Metal Treating*, 1952, **3**, Sept.–Oct., 6–8). The nature of carbide segregation is discussed, and its adverse effect on the toughness of high alloy tool steels is shown by tests carried out by the authors. Further tests showed that carbide segregation has an adverse effect on distortion and machinability.—P. M. C.

**Banded Structure.** G. Remy. (Commission d'Ingénieurs : *Centre Doc. Sidér. Circ. Inform. Tech.*, 1952, No. 5, 682–698). The salient features of the macro- and micro-structures of steel are discussed, and the formation of laminations after rolling is illustrated by micrographs. Examples of banded structure are given, and include hypereutectoid tool steels, before and after reheating, and constructional steels. The nature of carbide segregation and the influence of speed of cooling on the bands are mentioned. The ability of a steel to present a banded structure is studied, and a number of experimental results are quoted. Numerous photomicrographs are given. (18 references).—T. E. D.

**Duplex Structure in Steel.** (*Usine Nouvelle*, 1952, **8**, Sept. 25, 47). The author postulates the existence of a duplex structure in steels consisting of martensite, troostite or sorbite, together with a network of the old austenite grain boundaries. This hypothesis explains the observed phenomena associated with overheating and temper brittleness in alloy steels.

**Effect of Low Absorption Coefficient on X-Ray Spectrometer Measurements.** D. J. Keating and B. E. Warren. (*Rev. Sci. Instruments*, 1952, **23**, Oct., 519–522).

**Recrystallization Concepts in Metallography and Mineralogy.** K. F. Chudoba. (*Z. Metallkunde*, 1952, **43**, Sept., 337–338). A comparison is made between recrystallization in metals, with the formation of new crystals without change of phase, and in the varied phenomena in mineralogy classed as recrystallization, where in many cases a partial or complete transformation to an amorphous phase takes place. The use of X-ray photographs in tracing phase transformations in minerals is mentioned.—L. H.

**Iron Atoms in the Service of the Electrical Engineer.** Sir Charles Goodeve. (Kelvin Lecture: *Proc. Inst. Elect. Eng.*, 1952, **99**, Nov., 225–232). The structure of the iron atom is first described. Iron owes many of its special properties to the unpaired electrons in the 3*d* state, and to the fact that it does not normally crystallize in the densest spherical packing. The formation of dislocations is illustrated by bubble models, and it is shown how dislocations allow plastic flow. The mechanism of work hardening, the strengthening influence of iron carbide, and the effect of carbon and small amounts of nitrogen on complex dislocations are next explained. The need for steels resistant to high temperatures in modern generating plant is stressed, and the influence of alloying elements such as molybdenum and chromium in building up resistance to creep, forming stable carbides and resisting corrosion at high temperatures is described. Finally, the magnetic properties of iron are discussed and interpreted.

**The Growing of Single Crystals of Magnetite.** J. Smiltens. (*J. Chem. Phys.*, 1952, **20**, June, 990–994). Large, single crystals of magnetite, 1 cm. in dia. and up to 4·3 cm. long, of high purity and perfection, have been grown from the melt. The density at 20° C. is 5·185, *i.e.*, 99·58% of the X-ray density. The composition corresponds to stoichiometric $Fe_3O_4$ within analytical error. Phase-diagram considerations, growing procedure, methods of chemical analysis, and composition data are discussed.

**On the Structure of a Metallic Surface (According to Recent Investigations with Electron Radiation).** H. Raether. (*Metalloberfläche*, 1952, **6**, Aug., A113–A119). Diffraction patterns obtained by electron radiation, used on account of its low penetrating power compared with X-rays, were used to interpret the effect in or near a mechanically worked surface. It was found that a maximum distortion, with a fine crystalline structure, was obtained to a depth of about 10Å., with a normal undistorted structure after about 10μ, in the case of metals. The author also describes investigations by the electron microscope and electron radiation, into the effect of electrolytic polishing on various metals.—L. H.

**Researches on the Mechanism of Oxidation of Single Crystals of Iron.** J. Bardolle and J. Bénard. (*Rev. Mét.*, 1952, **49**, Sept., 613–622). At low oxygen pressures and high temperatures (850° C.) oxidation occurs preferentially at certain points producing epitaxial nuclei, and, on increasing the pressure slightly, a continuous epitaxial film is formed. Reaction rate varies considerably with orientation, and film thickness decreases rapidly as the temperature falls.—A. G.

**The Preparation of Single Crystals of Metals.** M. N. Parthasarathi and B. R. Nijhawan. (*Metal Market Review*, 1952, **5**, Sept. 8, 9–12; Sept. 15, 9–16). A detailed review of methods of preparation of single crystals of metals is made. (130 references).—B. G. B.

**Review of the Main Applications of Radiocrystallography in Metallurgy.** J. Papier. (*Bull. Cercle Études Mét.*, 1952, **6**, Sept., 57–82). A general survey is given of the fundamentals of X-ray crystallography, and types of equipment are described. Applications in metallurgical analysis, the determination of phases in alloys, and for following phenomena of diffusion, deformation, and precipitation are mentioned.

**On Light Figures of Single Crystals of 3% Silicon Iron and Pure Iron.** M. Yamamoto and J. Watanabé. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, Mar., 136–140). [In Japanese]. Light figures produced by the three principal crystallographic planes of single crystals of 3%-Si iron and pure iron etched

with various aqueous solutions were observed. Figures suitable for determination of crystal orientation were obtained when ammonium persulphate or ferric chloride etches (the latter for pure iron) were used.—K. E. J.

**Several Experiments Relating to the Production of Iron Single Crystals by the Recrystallization Method.** M. Yamamoto and R. Miyasawa. (*Nippon Kinzoku Gakkai-Si*, 1942, **16**, June, 300–304). [In Japanese]. Round bars of commercially pure iron and soft steels were heated to 1000° C. in hydrogen, and held for two days ; selected specimens were then drawn and annealed at 880° C. for 2–3 days. Best results were obtained at 4% elongation. Observations showed that carbon diffuses faster in α- than in γ-iron, grain growth during heating is less than at 1000° C., decarburization velocity is inversely proportional to diameter, and grain growth increases with purity. (22 references).—K. E. J.

**Production of Single Crystals of Iron–Aluminium Alloys by the Strain-Anneal Method.** M. Yamamoto and R. Miyasawa. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, June, 305–309). [In Japanese]. Production of circular crystals, 3 mm. in dia., from alloys of <6% Al was studied. Optimum decarburization temperature and elongation fell from 970° C. and 4% for electrolytic iron to 900° C. and 2% for the 6%-Al alloy, whilst optimum annealing temperature rose from 880° to 1000° C. Suitable reagents, and results of etching, are reported. (23 references).—K. E. J.

**Imperfections in Nearly Perfect Crystals.** (*Symposium at Pocono Manor*, Oct. 12–14, 1950 : John Wiley and Sons, Inc., New York ; Chapman and Hall, Ltd., London, 1952). This symposium was sponsored by the Committee on Solids of the Division of Physical Sciences of the National Research Council.

The papers presented were :

**Imperfections in Nearly Perfect Crystals: A Synthesis.** F. Seitz. (3–76).

**On the Geometry of Dislocations.** W. T. Read, jun. and W. Shockley. (77–94).

**Imperfections from Transformation and Deformation.** C. S. Barrett. (97–128).

**Experimental Information on Slip Lines.** W. T. Read, jun. (129–151).

**X-Ray Diffraction Studies of Cold Work in Metals.** B. E. Warren and B. L. Averbach. (152–172).

**Mechanical Strength and Creep in Metals.** N. F. Mott. (173–196).

**The Influence of Dislocations and Impurities on the Damping and the Elastic Constants of Metal Single Crystals.** J. S. Koehler. (197–216).

**Relaxation Effects in Ionic Crystals.** R. G. Breckenridge. (219–245).

**Studies of Alkali Halides by Photoelectric Methods.** L. Apker and E. Taft. (246–260).

**Diffusion in Alloys and the Kirkendall Effect.** J. Bardeen and C. Herring. (261–288).

**Theory of Diffusion.** C. Zener. (289–314).

**Surface and Interfacial Tensions of Single-Phase Solids.** J. C. Fisher and C. G. Dunn. (317–351).

**Dislocation Models of Grain Boundaries.** W. T. Read, jun., and W. Shockley. (352–376).

**Interphase Interfaces.** C. S. Smith. (377–401).

**Substructures in Crystals.** A. Guinier. (402–440).

**The Properties and Effects of Grain Boundaries.** B. Chalmers. (441–450).

**Movement and Diffusion Phenomena in Grain Boundaries.** R. Smoluchowski. (451–475).

**Relations between Transformation Kinetics, Structure and Mechanical Properties of Chromium–Vanadium Steels.** M. Kroneis, R. Gattringer and H. Krainer. (*Stahl u. Eisen*, 1953, **73**, Jan. 1, 22–30). The relations between hardenability, structure, and mechanical properties are discussed. The influence of hardening temperature on their transformation kinetics is indicated. Higher hardening temperatures lead to greater increase of hardness in the through-hardening of heavy sections, principally because of a delayed pearlitic transformation. A ferrite-free heat-treated structure is essential for the best values of notched-bar-impact/tensile and yield-strength/tensile strength ratios. With conventional procedures, this condition is fulfilled at a quench hardness of over Rockwell C45. With a purely martensite/intermediate-stage structure, the amount of martensite determines the mechanical properties.—J. P.

**Crystal Orientation during the Transformation of Iron.** H. Neerfeld. (*Arch. Eisenhüttenwesen*, 1952, **23**, Nov.–Dec., 471–473). Observations of the $\gamma$–$\alpha$ transition have shown that relative orientation of the α-iron with respect to its parent γ-iron may vary with experimental conditions and a number of different transition mechanisms have been proposed. A mechanism put forward for transformation under tensile stress can, however, be related to that suggested previously by Nishiyama if consideration is given to the influence of external forces, particularly shear stress. It is therefore more convenient to speak of different orientation relationships than of different mechanisms, and to describe the occurrence of the different relationships as being the results of one basic transformation process modified by other factors.—J. P.

**Exciting the Intermediate Stage Transformation of Steel by Small Amounts of α-Iron.** E. Jellinghaus. (*Arch. Eisenhüttenwesen*, 1952, **23**, Nov.–Dec., 459–470). The transformation of two alloyed steels, containing manganese and nickel, has been studied. The transformation rate decreases with increasing austenitizing temperature. The tendency of the austenite in a steel with 0·9% C, 2·0% Mn, to decompose in the intermediate stage is increased by cooling rapidly to just below the martensite point and then reheating to the intermediate stage transformation temperature. Steels with 0·3% C, 3·5% Ni, and with 1% C, 1% Mn, 5% Cr, show the same increase in austenite decomposition rate when given the same kind of treatment. Steel with 1·2% C, 3·2% Mn can be quenched to room temperature and still remain fully austenitic. By tempering at 300° C., the austenite decomposes after an induction period of several hours.—J. P.

**On the Stabilization of the Austenite for the Martensite Transformation.** M. Okamoto and R. Odaka. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, Feb., 81–86). [In Japanese]. Quantitative results are presented, for a steel containing 1% C and 1·6% Cr, on the magnitude of the temperature arrest in the martensite transformation resulting from interrupted cooling. The effect of the holding time at constant temperature has also been evaluated. It is concluded that the stabilization is closely related to formation of Preston Guinier zone-like clusters within the austenitic solid solution during incubation for the bainite transformation. (22 references).

**Effect of Initial Grain Size in the Pearlite-Austenite Transformation.** M. I. Maslennikova and Ya. R. Rauzin. (*Zhurnal Tekhnicheskoi Fiziki*, 1950, **20**, 6, 692–697). Using a ball-bearing steel (C 1·02%, Cr 1·56%), experimental data were obtained on the exact position of the nucleation of austenite, and the influence of grain size in the pearlite → austenite transformation. The austenite grains begin to form at interfaces which are distinguished by a higher energy level and the nucleation proceeds along the boundaries of the ferrite grains. Coarse globular structures delay the nucleation of austenite.—R. A. R.

**An Interpretation of Hysteresis Loops in $A_3$ and $A_4$ Transformations of Pure Iron.** K. Honda and M. Satô. (*Proc. Japan Acad.*, 1951, **27**, Dec., 637–642). [In English]. Calculations and experimental results are given, concerning the expansion of iron on heating. The irreversibility of the $A_3$ and $A_4$ transformations, and their elevation and depression, are explained in terms of internal stresses. Parameters of the hysteresis loops are calculated. New definitions of $A_C$ and $A_R$ points are suggested.—K. E. J.

**The Effect of Transformation Pressure on Latent Heat of Fusion of Metals.** K. Honda and M. Satô. (*Proc. Japan Acad.*, 1950, **26**, Jan., 29–31). [In English]. In calculations of change of latent heat under pressure, the internal stress accompanying transformation can be regarded as equivalent to an external mechanical pressure. Calculated changes agree well with observations for several metals.—K. E. J.

**The Effect of Transformation Pressure on the Difference of Specific Volumes in Liquid and Solid States of Metals at Melting Points.** K. Honda and M. Satô. (*Proc. Japan Acad.*, 1950, **26**, Jan. 32–33). [In English]. Stresses accompanying transformation may be regarded as equivalent to external applied pressures. Derived formulæ give a method for calculating the changes under pressure in the difference of specific volumes, which gives satisfactory agreement with observations for several metals.—K. E. J.

**Diffusionless Martensitic Transformations in Alloys.** G. V. Kurdyumov. (*J. of Technical Physics, U.S.S.R.*, 1948, **18**, 8, 999–1004). The author regards martensite as a strongly supersaturated solid solution of carbon in α-iron which exists

only in the metastable state. He shows that the transformation takes place without change in the concentration of the solid solution, and he therefore calls it a diffusionless transformation. Investigations are reported which indicate that this transformation is not unique but is of a type encountered frequently in other metals and alloys. (50 references).

**On the Fundamental Concepts of the Theory of Phase Transformations in Solids.** V. I. Arkharov. (*Izvestiya Akademii Nauk S.S.S.R., O.T.N.*, 1951, **11**, 1744–1751). A critical review of concepts relating to mechanisms of phase transformation in alloys, and particularly in steel, is given. The author discusses the mechanism of phase transformation on the basis that all structural changes in solids derive from two elementary kinds of displacement of individual atoms from lattice nodes to internodes, due either to the change in the thermal-vibrational energy (diffusion) or to the action of elastic forces (plastic deformation).—V. G.

**Contribution on the Stabilization of Austenite.** J. Plateau, J. Duflot, and Ch. Crussard. (*Rev. Mét.*, 1952, **49**, Nov., 815–834). The effect of various thermal treatments on hypereutectic chromium or nickel steels has been studied. Two types of stabilization (*i.e.*. raising the $M_s$ point) are distinguished, direct and inverse, favoured by slow and rapid quenching respectively. Direct stabilization is accompanied by contraction and structural hardening of the austenite. Inverse stabilization appears when the quenching rate is raised and is either a direct effect of quenching stresses or a preliminary stage of direct stabilization. Both types are explained by the influence of dislocations on the growth of martensite plates.—A. G.

**The Order-Disorder Transformation in Ternary Alloys.** E. Josso. (*Rev. Mét.*, 1952, **49**, Oct., 727–732). Ternary ferronickels with 5% Cu or 4% Mo and ferrocobalt alloys have been studied by noting the volume changes accompanying the order-disorder reaction. Forged, cast, and sintered ferronickel alloys are compared and the relation between resistivity and degree of order determined. Chromium hinders the order transformation in iron–cobalt alloys.—A. G.

**Two-phase Equilibrium in Binary and Ternary Systems. IX. Derivation of the General Equation Defining a Small Change at Equilibrium.** R. F. Strickland-Constable. (*Proc. Roy. Soc.*, 1952, **214A**, Aug. 7, 36–43). An equation is derived which defines a small change in a two-phase two-component system under equilibrium conditions. Equations are known for special cases in such systems, but the present equation is for the general case of transfer of a drop for any relative sizes of the phases. A method of calculating partial differential relationships is also described.—K. E. J.

**On the Ageing Change of Austenite during Incubation Period of Isothermal Transformation.** K. Monma, S. Uemura, and M. Hirata. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, June, 328–333). [In Japanese]. Changes of electrical resistance and magnetic properties during isothermal ageing were studied for high-speed and other special steels. At the troostite formation temperature, resistivity fell, due to carbide precipitation and the $\gamma \rightarrow \alpha$ transformation. Between $Ar_1$ and $Ar_2$ there was little change. At $Ar_2$, resistivity increased, due to the gradual $\gamma \rightarrow$ martensite transformation.—K. E. J.

**Research on the Relation between Cast Iron and Oxygen: the Mechanism of White Cast-Iron [Formation] by Oxygen.** K. Iwase and M. Homma. (*Nippon Kinzoku Gakkai-Si*, 1952, **16**, Feb., 111–116). [In Japanese]. The mechanism of white cast iron formation is explained on the basis of atomic arrangement and the modified equilibrium diagram. In liquid iron, oxygen atoms behave partly as free oxygen and partly as Fe–C–O–Fe clusters : these prevent the freezing of the melt at the austenite-graphite eutectic, and consequently the melt freezes as white cast iron at the austenite-cementite eutectic point . (14 references).—K. E. J.

**On the Equilibrium Diagram of the Ternary Alloy System of Iron, Manganese and Carbon.** M. Isobe. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, A, 1951, **3**, Oct., 540–621). [In English]. The diagram for the Fe–Mn–C system was completely determined, using thermal analysis, change in volume magnetic analysis, microscopic examination and X-ray analysis : materials used were electrolytic iron, distilled manganese, and sugar charcoal. Graphical results are presented. 7 kinds of primary crystal surface are identified, viz., δ-Fe, γ-Fe, C, δ-Mn, γ-Mn, β-C and α-C ternary solid solutions. The intersections produce six peritectic lines, four eutectic lines, two peritecto-eutectic points, and one ternary eutectic point. In the solid state, three peritecto-eutectoid and four eutectoid reactions were distinguished.—K. E. J.

**Principles Involved in the Formation of Iron Alloys.** K. W. Andrews. (*Metal Treatment and Drop Forg.*, 1952, **19**, Oct., 425–432 ; Nov., 489–498). A number of empirical relationships are proposed which may be of value in establishing the fundamental principles involved in the formation of iron alloys. The effect of atomic radii and general relation to the periodic system (Wever's classification) is discussed, and further development of this classification and some qualitative and quantitative relationships are outlined. Progress in the applications of thermodynamic functions to the $\alpha \rightleftharpoons \gamma$ transformation in binary and ternary alloys, and of modern electron theory to explain the metallic bond and alloy formation, is discussed. (44 references).—P. M. C.

**On the Superlattice of Binary Alloys with a Large Unit Cell and Many-Component Alloys. II—On the Superlattice of Many-Component Alloys.** H. Sato. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1951, **4A**, Apr., 150–159). [In English]. General characteristics of superlattice in multi-component alloys are discussed from the standpoint of formal theory. The general properties of these alloys may be represented by those of ternary alloys, and are deduced by arguments similar to those for ternary alloys with a large unit cell.—J. G. W.

**On the Superlattice of Primary Alloys with a Large Unit Cell and of Many-Component Alloys. I—On the Superlattice of Primary Alloys with a Large Unit Cell.** H. Sato. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1952, **4A**, Feb., 1–13). [In English]. General characteristics of binary alloys are discussed in terms of a formal theory in which the ordering energy is composed of the sum of the interaction energies of definite magnitude between each pair of atoms.—J. G. W.

**On the Condition of Synthesis for $Fe(CO)_5$.** H. Kojima. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1952, **4A**, Feb., 85–95). [In English]. Suitable condition of synthesis for $Fe(CO)_5$ was determined from chemical data of the equilibrium state and is discussed qualitatively from the point of view of reaction velocity.—J. G. W.

**On the Stabilization of Austenite with Respect to the Martensite Transformation.** G. N. Bogacheva and V. D. Sadovskii. (*Doklady Akademii Nauk S.S.S.R.*, 1952, **83**, 4, 569–572). An investigation was made to test the theory that there is a stabilizing temperature $M_{st}$ below which holding is accompanied by stabilization of austenite in the martensite transformation. and that the $M_{st}$ point may be above or below the temperature $M_s$ at which transformation begins. The results showed that holding austenite at room temperature, or at 200° C., does not affect the transformation during subsequent cooling, but if the specimen already contains some martensite the effect is very marked. After holding for 10 min. at room temperature a specimen in which martensite had appeared at below 0° C., the temperature at which transformation was resumed on subsequent cooling was considerably reduced.

**Solid Solutions: Classification of the Solubilities of Elements in Iron.** I. I. Kornilov. (*Iron Steel*, 1952, **24**, Dec., 517–521). The binary systems of iron with the other elements of Group 8 of the Periodic Table from stable austenitic solid solutions at room temperature ; third and fourth elements, partially soluble in these face-centred metals, form ternary and quaternary systems with complex, limited austenitic solid solutions at room temperature. From a consideration of the atomic diameters of various elements and their solubilities in the face-centred metals, the author establishes two types of ternary diagram and four types of quaternary diagram, and calculates the possible number of systems of each type.—G. F.

## CORROSION

**The Work of the Protective Coatings (Corrosion) Sub-Committee.** F. Fancutt and J. C. Hudson. (*Corrosion*, 1952, **8**, Nov., 366–374). The results of investigations of protective coatings for structural iron and steel extending over 20 years are surveyed. Correct surface preparation before painting has been shown to be vitally important and the value of inhibitive priming paints has been demonstrated. The formulation of anti-corrosive paints for both land and marine use continue to be studied in collaboration with the paint industry.—J. F. S.

**Developments in Corrosion during the Past Fifty Years, A Brief Review.** H. H. Uhlig. (*J. Electrochem. Soc.*, 1952, **99**, Oct., 275c–276c). The development of corrosion research

and prevention from 1903 to the present time and outstanding discoveries in this period are reviewed.—J. P.

**Corrosion.** M. G. Fontana. (*Indust. Eng. Chem.*, 1952, **44**, Nov., 101A–104A). Corrosion resistance to nitric acid of quench-annealed 18/8–S stainless steel, in cast and wrought form, has been examined over a wide range of temperature and acid concentration. Resistance is excellent to all acid concentrations at up to 80° F., and to boiling acid up to 50% strength. Sensitized 18/8–S is less resistant. The steels containing niobium or titanium behave similarly, but those containing molybdenum or higher silicon have lower resistance.

**Incipient Corrosion of Steel.** F. Hargreaves. *Metal Treatment and Drop Forg.*, 1952, **19**, Sept., 385–390). Filiform corrosion has been induced by the author on polished steel specimens and the thread-like growth traced microscopically. The effect on growth of non-metallic inclusions, and droplets of various liquids, and the influence of surface protectives have also been studied.—P. M. C.

**Organic Materials vs. Corrosion.** K. Tator. (*Chem. Eng.*, 1952, **59**, Dec., 147–156). Various classifications are introduced to aid selection of suitable protective coatings.—T. E. D.

**Corrosion Inhibitor Checklist.** M. Brooke. (*Chem. Eng.*, 1952, **59**, Sept., 286–287). Suitable inhibitors to use with a number of ferrous and non-ferrous metals in various environments are listed. (41 references).—T. E. D.

**Inorganic Corrosion Inhibitors in Acid Solution.** C. V. King, E. Goldschmidt, and N. Mayer. (*J. Electrochem. Soc.*, 1952, **99**, Oct., 423–426). In dilute hydrochloric acid with potassium nitrate as a depolarizer, iron, zinc, and cadmium dissolve at approximately the maximum rate controlled by the convection and speed of diffusion of hydrogen ions. Dissolution rates can be reduced to small values by addition of dichromate, molybdate, or tungstate. The rates can be further reduced by addition of a soluble fluoride in the presence of dichromate.—J. P.

**Research Work Carried Out in Italy on the Corrosion of Metals.** L. Cavallaro. (*Soc. Roy. Belge Ing., Mém.*, 1952, No. 3, 15–36). Published papers on the corrosion of metals are discussed, particular reference being made to those by Italian workers. (100 references).—B. G. B.

**The Belgian Centre for Corrosion Studies 'Cebelcor'.** M. Pourbaix. (*Soc. Roy. Belge Ing., Mém.*, 1952, No. 3, 5–10). An account is given of the activities of this Belgian centre. A number of committees have been formed, or are being formed, to deal with different corrosion problems. Six committees have already been formed and are investigating the protection of metals by electrodeposition, the cathodic protection of metals, corrosion of steel piles, the resistance to corrosion of alloy steels, the mechanism of the incrustation of metallic surfaces by salts in water, and studies in connection with the use of concrete.—B. G. B.

**Measurement of the Corrosion Rate of a Metal from Its Polarizing Characteristics.** W. J. Schwerdtfeger and O. N. McDorman. (*J. Electrochem. Soc.*, 1952, **99**, Oct., 407–413). Steel electrodes have been exposed in soils and corrosion currents calculated from the breaks in cathodic and anodic polarization curves determined at periodic intervals. The weight losses calculated therefrom differed by approximately 4% from actual weight losses. Electrolytic measurements indicate that there is a relatively fixed relation between the corrosion rate of steel in soils and the current required for cathodic protection. A connection has been found between the slopes of the cathodic polarization curves and the corrosion rate.—J. P.

**A Polarographic Study of the Influence of Temperature on the Rate of Oxygen Consumption by Iron, Lead and Zinc.** P. Delahay, C. F. Pillon, jun., and D. Perry. (*J. Electrochem. Soc.*, 1952, **99**, Oct. 414–416). Rates of consumption of oxygen by iron, lead, and zinc immersed in an acetate buffer at *p*H 5·0 have been determined at various temperatures. The rate of diffusion of oxygen to the metal surface was the predominent factor controlling the over-all rate, but the influence of the rate of the chemical reaction at the surface was by no means negligible.—J. P.

**Protection Against Rust.** O. Gerhardt. (*Werkstoffe u. Korrosion*, 1951, **2**, Dec., 444–446). A survey is made of protective coatings used for steel. Old-established methods, and modern developments, including the use of silicones in the U.S.A., are outlined.—L. H.

**Wetting of Metals by Water.** J. L. v. Eichborn. (*Werkstoffe u. Korrosion*, 1951, **2**, June, 212–221). The author discusses experiments on the equilibrium of wetting of air, water and metal, in its application to the question of metallic corrosion. Metals studied include gold, silver, platinum, and mercury, and the effect of adsorption of atmospheric oxygen by the metals is studied. The treatment is in general qualitative.—L. H.

**Alteration of Corrosion by Means of Wetting Agents. II.—The Influence of Non-Ionizing Wetting Medium.** L. Piatti. (*Werkstoffe u. Korrosion*, 1951, **2**, Dec., 441–444). The mechanism of the inhibition of the corrosion of plain steel by tap water, by the use of wetting agents, is discussed. Iron-ionizing agents are more effective than anion-active ones ; the efficiency in reducing the surface tension of the water is increased by a higher concentration, but chemical-composition is the overriding factor.—L. H.

**The Speed of Solution of Iron in 0·1/N Hydrochloric Acid in the First Seconds.** H. Grubitsch and H. Väyrynen. (*Werkstoffe u. Korrosion*, 1951, **2**, Oct., 362–375). The higher initial velocity of solution of ground iron test pieces is attributed to a surface oxide effect ; the high rate of solution in an oxide-free surace obtained in a hydrogen atmosphere is explained by increased reactivity of surface iron atoms. The solubilities of ground and coarse-filed specimens in the initial stages are compared.—L. H.

**A Survey of the Electrochemical Properties of Metals.** M. Pourbaix. (*Ossature Métallique*, 1953, **18**, Jan. 47–56 ; Feb., 98–113). Electrochemical equilibrium diagrams with respect to water and hydrogen peroxide, for several metals, including iron, are presented and considered.—P. F.

**Corrosion Protection in Light Steel Structures.** W. Wiederholt. (*Werkstoffe u. Korrosion*, 1951, **2**, Oct., 372–377). The types and amounts of corrosion likely to be encountered are first described, and a survey is made of metallic and organic protective coatings which may be employed.—L. H.

**Corrosion of Structural Spot Welds.** B. Karnisky, E. Kinelski, and E. Gruca. (*Welding J.*, 1952, **31**, Oct., 903–916). An investigation of the corrosion phenomena in spot-welded joints of low-alloy, high-tensile steel is reported. The results indicate that spot welds may start to fail by corrosion cracking in as little as one year's time unless proper weld sealers are used in the joint and some form of regular maintenance is performed.—U. E.

**Phase Boundaries, Particularly their Importance in Corrosion.** R. Auerbach. (*Werkstoffe u. Korrosion*, 1951, **2**, Oct., 365–367). The initiation of corrosion at phase boundary lines is discussed ; adsorption at boundary phases and lines respectively inhibits corrosion by lowering free energy. Typical examples are given ; gravity and electrokinetic potentials have maximum values at the phase boundary lines.—L. H.

**Evans Cells with Varying Oxygen Aeration.** K. Wickert, H. Wiehr and W. Pfau. (*Werkstoffe u. Korrosion*, 1951, **2**, July, 241–243). Experiments are described to trace the cause of the lack of reproducibility in current density found in oxygen concentration cells. The variation was found to be related to the turbulence caused by the oxygen.—L. H.

**Rust and Its Morphology.** O. Gerhardt. (*Werkstoffe u. Korrosion*, 1951, **2**, Apr., 129–131). Examples of rusted iron surfaces are examined by the vertical illumination microscope ; freshly deposited and older surface and underlayers are examined and discussed. As an illustration, a defective rusted hydraulic tube is investigated.—L. H.

**The Theory of the Oxidation of Metals and Alloys.** K. Hauffe. (*Werkstoffe u. Korrosion*, 1951, **2**, Apr., 131–139 ; June, 221–231 ; July, 243–249). A general survey is made of oxidation theories, with a large number of references to the literature ; in particular the theories of Wagner, Mott–Cabrera, and Hauffe and Wagner are discussed. In the light of this survey, the possibility of the evolution of non-scaling metals and alloys is investigated, and lines of research are suggested. (99 references).—L. H.

**Study of the Structure and Properties of the Ferrous Oxide Layer Formed on the Surface of High Purity Iron.** R. Collongues and G. Chaudron. (*Rev. Mét.*, 1952, **49**, Oct., 699–706). A study of the effect of impurities on the oxide film shows that with more than 0·1% oxygen in pure iron the oxide-metal interface becomes very irregular, while carbon promotes fissures in the film. X-ray examination and electrolytic polishing indicate that, on a single crystal of iron, oxidation produces a number of small crystals all having nearly the same orientation as the underlying crystal. The decomposition of ferrous oxide occurs by two mechanisms : (*a*) Above

450° C. with iron and magnetite appearing simultaneously ; and (*b*) at lower temperatures with a marked lag in the appearance of iron.—A. G.

**Constructional Materials for the Chemical Industry.** E. Franke. (*Werkstoffe u. Korrosion*, 1951, **2**, May, 173–181 ; July, 249–257). A survey is given in Part I of the literature dealing with the properties and applications of corrosion-resisting steels, and nodular cast iron, and with the mechanism and prevention of corrosion (121 references). Part 2 deals in a similar way with non-ferrous materials. (134 references).—L. H.

**Investigation of the Zinc-Iron Cell.** K. Wickert and H. Wiehr. (*Werkstoffe u. Korrosion*, 1951, **2**, May, 165–171). The effect on cathodic and anodic loss of various conditions was studied in a zinc-iron cell, the electrolytes being N/10/NaCl and N/1 HCl. The effects of changing current density, of the amount of metal in solution, and of the oxygen content at constant current density were investigated. The influence of the passivity of the metallic surfaces is briefly discussed.

**The Passivating of Tinplate.** W. Eilender. (*Werkstoffe u. Korrosion*, 1951, **2**, Aug., 289–292). Tinplates manufactured by hot dipping and electrolytic deposition were tested against sulphide attack, resistance to oxidation on heating, and atmospheric corrosion. Solutions of potassium permanganate and dichromate, and dilute-sulphuric acid with the addition of chromate and inhibitors, were successful as passivators only when wetting agents or phosphates were added. In these circumstances successful resistance to sulphide and oxidation attack was obtained up to 200° C.—L. H.

**A Preliminary Study of the Oxidation and Vapour Pressure of Chromium.** E. A. Gulbransen and K. F. Andrews. (*J. Electrochem. Soc.*, 1952, **99**, Oct., 402–406). The oxidation of chromium between 700 and 900° C. follows a parabolic rate law, the heat and entropy of activation being 66,300 cal./mole and 10·7–13·5 cal./° C./mole, respectively. As compared with other metals, chromium has a good oxidation resistance though inferior to beryllium and the nickel–chromium alloys. Chromium vaporizes *in vacuo* at an appreciable rate above 825° C., the rate not being affected by the presence of oxide or nitride films formed in the vacuum. The vapour pressure has been determined between 885° and 1015° C.—J. P.

**The Kinetics of Wüstite Formation in the Oxidation of Iron.** K. Hauffe and H. Pfeiffer. (*Z. Metallkunde*, 1953, **44**, Jan., 27–36). The mechanism of the formation of wüstite is first discussed. The applicability of Wagner's oxidation theory to the oxidation of iron in strongly oxidizing atmospheres, and the growth, independent of the thickness of the deposit, of FeO in $CO_2$–CO mixtures, is kinetically evaluated. The dependence of the velocity constants of wüstite formation on the atmospheric composition and the temperature is measured.

**Chemical Processes in Central Heating Installations.** G. Seelmeyer. (*Werkstoffe u. Korrosion*, 1951, **2**, Dec., 448–456).

**The Corrosion of Metals in Liquid Sulphur Dioxide.** J. Bollinger. (*Schweiz. Arch. Wiss. Techn.*, 1952, **18**, Oct., 321–342). Loss in weight tests were made on small plates of mild steel and other metals, by exposure to liquid $SO_2$ containing known amounts of water and oxygen ; the specimens were half-immersed in the liquid. In general, metals are only attacked by liquid $SO_2$ to an appreciable extent when this contains water. Oxygen played a direct and essential part in the corrosion process. The final reaction product for iron was $FeSO_4$, $7H_2O$. The losses in weight after 14 days in liquid $SO_2$ containing 1% of water and 0·28% of oxygen were 18 for mild steel and 0·0 g./sq. m. for 18/8 stainless steel. In a closed vessel the attack on mild steel stopped after a few days when all the water in the $SO_2$ had entered into the corrosion product. The solubility of water in liquid $SO_2$ increased uniformly from 0·5 wt.-% at −28° C. to 2·8 wt.-% at +33° C. If more water than this was present, separation into phases occurred and the steel was severely pitted. The solubility of oxygen in liquid $SO_2$ is much greater than in water. Several inhibitors were tested and urotropin was the most effective with a protective efficiency of 85% for mild steel.—J. C. H.

**Effect of Hydrogen Sulphide upon Turbine Blades.** A. Splittgerber. (*Vom Wasser*, 1949, **17**, 140–145). The causes of transverse cracks in 5% Ni steel turbine blades at a German power station were investigated and traced to attack by hydrogen sulphide formed by the dissociation of sodium sulphite at temperatures above 275° C.—R. A. R.

**High Temperature Corrosion Rates of Several Metals with Hydrogen Sulphide and Sulphur Dioxide.** M. Farber and D. M. Ehrenberg. (*J. Electrochem. Soc.*, 1952, **99**, Oct., 427–434). The corrosion rates at temperatures above 1000° K. have been determined for copper, silver, Inconel, nickel, stainless steel, iron, tungsten, molybdenum, and tantalum in atmospheres of $H_2S$, $SO_2$, and CO. The metals most easily corroded in $H_2S$ were Inconel, iron, copper, and stainless steel, whereas tungsten, molybdenum, and tantalum offered most resistance. Inconel was very resistant to $SO_2$ but tungsten, tantalum and molybdenum were easily corroded. The corrosion rate of iron in $H_2S$ decreased in the presence of CO.—J. P.

**Mechanism of the Action of Ionized Solutions of Hydrogen Sulphide on Iron and Steel.** P. Bastien and P. Amiot. (*Compt. Rend.*, 1952, **235**, Nov. 3, 1031–1033). Immersion in aqueous hydrogen sulphide solution caused brittleness in mild steels, original properties being recoverable at 100° C. with the evolution of gas. This is attributed to weak ionization producing hydrogen ions which diffuse into the metal, since embrittlement does not occur in a non-ionizing solvent such as benzene.—A. G.

**Performance of Pretreatment Primers as Revealed by Accelerated Weathering Tests.** (*Products Finishing*, 1952, **17**, Nov., 46–56). The behaviour of protective schemes on a variety of metals as revealed by scratch and bend tests after exposure of samples in the Weatherometer is tabulated and discussed. For the protection of steel, an etch primer followed by baked enamel proved superior to (*a*) phosphatizing and enamel, (*b*) red oxide primer and enamel, and (*c*) phosphatizing, red oxide and enamel.—J. P.

**Increase in Corrosion Resistance of Phosphate Coatings upon Subseqent Treatment with Pore-Filling Substances.** W. Machu. (*Archiv für Metallkunde*, 1948, **3**, 10, 335–340). The possibilities of improving the protective value of phosphate coatings on iron and steel were investigated. Two methods were tested : (1) Precipitation of insoluble inorganic compounds in the pores of the phosphate coating ; and (2) conversion of a portion of the reagent left in the pores of the coating during phosphatizing into insoluble inorganic compounds. The effect of such additional treatment was checked by corrosion tests.—V. G.

## ANALYSIS

**Determination of Chromium by Oxidation in the Presence of Silver Nitrate.** S. Lynn and D. M. Mason. (*Analy. Chem.*, 1952, **24**, Nov.. 1855). A method is outlined for the determination of 0·1 to 10 mg. of chromium in which tripositive chromium is oxidized to the hexapositive state by means of fuming perchloric and sulphuric acids at 200° to 220° C. with the addition of silver nitrate. This results in a more quantitive oxidation than other methods quoted.—T. E. D.

**Titanic Chloride as an Intermediate in Coulometric Analysis.** P. Arthur and J. F. Donahue. (*Analy. Chem.*, 1952, **24**, Oct., 1612–1614). The apparatus, reagents, method and results, using titanic chloride as an intermediate in coulometric estimations of iron samples are described. The results compare favourably with the ferric oxide gravimetric method.

**Determination of Zirconium in Steels using *p*-Bromo- or *p*-Chloromandelic Acid.** J. J. Klingenberg and R. A. Papucci. (*Analy. Chem.*, 1952, **24**, Nov., 1861–1862). *p*-Chloro and *p*-bromomandelic acids were found to be just as accurate as mandelic acid, and easier to use, in the determination of zirconium in steels. All three reagents gave results agreeing with the generally accepted cupferron phosphate method.

**Determination of Nonmetallic Compounds in Metals.** H. F. Beeghly. (*Analy. Chem.*, 1952, **24**, Nov., 1713–1721). Published methods of isolation, identification and determination of non-metallic compounds in metals are reviewed and information is given on the separation of nitrogen compounds from steel by the ester-halogen method. (113 references).—T. E. D.

**Important Developments in Spectrophotometry.** G. S. Egerton. (*Chem. Age*, 1953, **68**, Jan. 10, 55–61). A comprehensive survey of ultra-violet and visible spectrophotometry instruments and infra-red spectroscopy equipment is given, with references. Recent developments in the quantitative applications of these methods are outlined.—T. E. D.

**Application of Absorption Spectrum of Ferric Acetate Complex to Determination of Iron.** W. Reiss, J. F. Hazel and W. M. McNabb. (*Analy. Chem.*, 1952, **24**, Oct., 1646–1648). The absorption characteristics of the ferric acetate complex in 50% acetic acid are given, and it is shown that an absorption maximum at 337·5 mμ in the ultra-violet region is

suitable for the quantitative estimation of iron. The analytical procedure is described.—T. E. D.

**Application of Powdered Samples to Graphite Electrodes for Spectrochemical Analysis.** R. C. Hughes. (*Analy. Chem.*, 1952, **24,** Sept., 1406–1409). The technique described provides a convenient means for excitation of solid samples by the high-voltage A.C. arc. Dispersions of the finely ground material in glycerol are applied to flat-ended graphite electrodes, and the glycerol is removed by heating. The resulting coating burns smoothly and reproducibly. The determination of silica in iron oxide and a mixed iron, manganese and zinc oxide product is studied here.—T. E. D.

**Aluminium Good Yardstick for Steel Grain Size.** J. W. Alden and J. G. Mravec. (*Steel*, 1952, **131,** Nov. 17, 96–101). A direct reading spectrometer allows rapid determination of aluminium content of high-quality steels ; as this value has been found to vary with the austenitic grain size it is used as a rapid means of quality control.—D. L. C. P.

**New Spectrochemical Excitation Unit: A Key to Essential Control in Boron Steels.** J. T. Rozsa and L. E. Zeeb. (*Steel*, 1952, **131,** Oct. 6, 92–97). A source which provides a low-voltage pulsating unidirectional arc which is ignited by the high-voltage spark every alternate half cycle has been developed for recording the 2496–78 boron spectral line. High sensitivity is obtained for low concentrations, short exposure times, and simple sample preparation. A high degree of precision in analysis is claimed.—A. M. F.

**A Simple Method of Titration of Nickel with Dimethylglyoxime Solution. II.** E. Block, G. Gad, and B. Krüger. (*Metall u. Erz*, 1941, **38,** July, No. 14, 325–326). This article gives further applications of a technique developed by the author by which a solution containing nickel is titrated with standard dimethylglyoxime solution, the end point being indicated by spotting on to a filter paper impregnated with this solution.—L. H.

**The Precipitation of Nickel and Cobalt Sulphides from Solutions Containing Iron.** H. Lauterbach. (*Metall u. Erz*, 1941, **38,** June, No. 11, 264–265). A liquor containing sulphates of iron, nickel, and cobalt, and 1·5% free sulphuric acid, was mixed with a fairly concentrated solution of sodium sulphide, when most of the nickel and cobalt, and a portion only of the iron, was precipitated; the proportion of iron was less if the containing vessel was closed, so that the generated hydrogen sulphide reacted with the liquor.—L. H.

**Notes on a Practical Type of Spectrograph with a Concave Grating.** P. Swings. (*Rev. Univ. Min.*, 1952, 9th series, **8,** Nov., 451). The author describes a method of spectroscopy in which the first order reflections from a concave grating are recorded photographically and the second order reflections are measured photoelectrically.—B. G. B.

**Experience with the Spectrochemical Method of Rapid Analysis.** T. K. Willmer. (*Stahl u. Eisen*, 1952, **72,** Nov. 6, 1443–1447). After reviewing the development of spectrochemical methods, the spectrographic equipment in the laboratory of an integrated steelworks is described. The required rapidity of operation has been achieved by the use of self-developed auxiliary equipment, the application of which is discussed. The cost of the installation and of individual estimations, and the staff, time and energy requirements are given. Finally, the possibilities of spectrographic analysis in a steelworks' laboratory are indicated.—J. P.

**Spectrographic Analysis of Low-Alloy Steels.** (*Iron Steel Inst. Special Report* 47, Sept., 1952). The report commences with a description of the spectrograph and the accessory equipment. The main types of electrode system in use are next considered and four methods of excitation are described, *viz.*, low-voltage D.C. arc, high-voltage A.C. arc, high-voltage spark sources, and controlled low-voltage discharge sources. The photographic techniques employed and the care necessary if accurate results are to be obtained are next discussed. A number of proposed plate-calibration techniques are reviewed and the procedure for measuring the time intensity is described. The classification and identification of spectral lines and the selection of line pairs for photometric measurement are next explained, and a list of recommended line pairs is given. The principle and use of the direct reading spectrometer are explained; the percentage of a constituent can be obtained in about 60 sec. For low-alloy steels, reproducibility of the order of 1% of the element content may be obtained—even less in some cases. The report concludes with a full description of a recommended method for the spectrographic analysis of low-alloy steels. (156 references).—B. G. B.

**Sampling of Pig Iron, Steel, Ferro-Alloys and Scrap.** K. Möhl. (*Arch. Eisenhüttenwesen*, 1952, **23,** Nov.–Dec., 433–438). The sampling of the above materials is used as an illustration of the responsible and variegated nature of the work of a sampler. It is shown that he must work in close co-operation with the analyst if the task is to be successfully accomplished.—J. P.

**Determination of Some Minor Elements in Lorraine Iron Ores.** J. Aubry, G. Turpin and G. Laplace. (*Rev Mét.*, 1952, **49,** Oct., 737–740). Methods based on the colorimetric estimation of the coloration due to various organo-metal complexes are outlined. Lorraine ores contain the following quantities (g./ton) of minor elements : Cr 65–150, Ni 75–120, Co 40–60, Cu 55–95, Pb 50–120, and Zn 240–380. The determination of the halogens and phosphate also present is described.—A. G.

**A Drop-Counting Fraction Cutter for Column Chromatography.** D. Rivers and P. R. Payne. (*Instrument Practice*, 1953, **7,** Jan., 206–208).

**The Determination of Total Sulphate in Nickel Plating Solutions Using Di-Sodium Ethylenediamine Tetra-Acetate.** K. E. Langford. (*Electroplating*, 1953, **6,** Feb., 41–42, 58).

**Simultaneous Determination of Iron and Aluminium in Galvanising Zinc.** V. H. Hardy. (*Métaux–Corrosion–Indust.*, 1952, **27,** Dec., 515–518).

**Continuous Photometric Determination of Carbon Dioxide in Gas Streams.** W. D. Maxon and M. J. Johnson. (*Analy. Chem.*, 1952, **24,** Oct., 1541–1545). The method utilizes the equilibrium between $CO_2$ and the aqueous bicarbonate ion using phenol red as indicator.—T. E. D.

**Determination of Iron in Used Lubricating Oils.** J. E. Barney and W. A. Kimball. (*Analy. Chem.*, 1952, **24,** Oct., 1548–1550). The spectrochemical analysis of 0·001 to 0·1% iron in oil is fully described. A buffered D.C. arc gives an accuracy of 10% free from interferences. (17 references).

**Manometric Gas Analysis Apparatus.** J. N. Pitts, jun., D. D. DeFord, and G. W. Recktenwald. (Analy. Chem., 1952, **24,** Oct., 1566–1568). The operation of an apparatus for the analysis of water, carbon dioxide and oxygen in a gas sample of 2–6 ml., using beads of reagents ($P_2O_5$), KOH and yellow phosphorus) is described. The pressure change of the gas at constant volume is measured.—T. E. D.

**Continuous Determination of Small Percentages of Methane in Gases.** H. Nash, jun., J. R. Hall, H. Y. Allgood, and J. A. Burnett. (*Analy. Chem.*, 1952, **24,** Oct., 1650–1652). A method is described for continuously analysing a gas for methane, after removing $CO_2$ and CO, by oxidation of the methane to $CO_2$, which is then determined electroconductometrically.—T. E. D.

**A Wet-Combustion Method for the Determination of Chlorine in Coals.** R. Belcher. (*Anal. Chim. Acta.*, 1953, **8,** Jan., 16–21).

**Chemical Analysis and Physical Testing of Solid Fuels: Expressing the Results.** W. Farafonow. (*Iron Coal Trades Rev.*, 1952, **165,** Nov. 14, 1083–1084). Results of chemical analysis or physical testing of solid fuels may be expressed in relation to the as-received, air-dried, dry, or dry ash-free fuel. Lack of uniformity in the method of reporting such results, and the confusion which often arises, leads the author to recommend a standard notation with symbols representing each property or subject of analysis, and indices denoting the condition of the fuel.—G. F.

**Conductometric Determination of Sulphur in Coal.** J. O. Elphick and T. Gerson. (*Fuel*, 1952, **31,** Oct., 438–444). A method is described for the conductometric titration of sulphur from coal burnt in a bomb calorimeter. The method is claimed to be of ample accuracy for routine analysis.—B. G. B.

**The Determination of Alumina in Refractory Materials.** H. Pranter and K. Konopicky. (*Radex Rundschau*, 1948, No. 3–4, June, 61–63). The presence of very small amounts of alumina in silica refractories strongly reduces their heat resistance, particularly in the presence of FeO, thus making accurate methods of alumina determination essential. Two variations of a speedy direct method are given, one for materials with predominant silica, the second for low or medium silica contents.—E. C.

## HISTORICAL

**Some Pages from the History of the Luxemburg Metallurgical Industry under the Austrian Regime.** A. Sprunck. (*Rev. Tech. Luxembourg*, 1952, **44,** Oct.–Dec., 228–239).

**Leonardo da Vinci and the Science of Founding.** G. Somigli. (*Fonderia Ital.*, 1952, **1,** Dec., 227–232). This article commemorating the fifth centenary of Leonardo da Vinci, describes the techniques developed by him in casting statues and canons. A description is also given of the first reverberatory furnace.—M. D. J. B.

**The Slags of Metallurgists in Former Times.** (*Echo Mines*, 1952, May, 317–318). A historical survey is given of early iron-making practice in France and the composition of slags obtained.—T. E. D.

**The Pedigree of the Blast Furnace.** J. W. Gilles. (*Arch. Eisenhüttenwesen*, 1952, **23,** Nov.–Dec., 407–415). The development of the blast furnace is traced from pre-Christian eras to the time when the shape and method of working became essentially what they are today.—J. P.

**Early Steel.** H. R. Schubert. (*Man and Metal*, 1953, **30,** Jan. 8). Recent discoveries in Anglesey of segments of steel tyres for chariot wheels dated from about 150 B.C. to 50 A.D., have re-opened the whole question of the antiquity of steel manufacture in Great Britain. The author discusses the probable manufacture of such steel, and then mentions records of steel " cakes " bought in 1300 and later.

**The Centenary of the Hüttenwerke Phoenix at Ruhrort-Meiderich.** W. Steinberg, F. A. Georgen and T. Heuss. (*Stahl u. Eisen*, 1952, **72,** Dec. 4, 1596–1604). Three speeches at the celebration of this centenary are reported.—R. A. R.

**A Great French Metallurgist: Pierre Dejean (1877–1938).** (*Aciers Fins Spec. Franç.*, 1952, June, 109–110). The education and career of this French metallurgist are traced.—E. C. S.

**Paul Louis Toussaint Héroult, The Great French Metallurgist. (1863–1914).** (*Aciers Fins Spéç. Franc.*, 1952, Mar., 103–104). The article deals with the education and career of this metallurgist.—E. C. S.

**A Famous French Metallurgist: Alexandre Pourcel (1841–1934).** (*Aciers Fins Spec. Franç.*, 1952, Dec., 104–108). The education and career of this French metallurgist are briefly described.—E. C. S.

**The First Iron Steamer.** H. P. Spratt. (*Engineer*, 1953, **195,** Jan. 30, 163–164). Some particulars of early iron vessels are given, with special reference to the first iron steamer the " Aaron Manby ", the hull of which was built of ¼ in. iron plates at Horseley ironworks. in 1821—R. A. R.

## ECONOMICS AND STATISTICS

**Statistics—France, The French Union, Saar.** (*Annales des Mines*, 1952, **141,** Nos. 9–10, 1–141). The whole of this issue is devoted to tables of production, imports and exports of coal, coke, iron ore, pig iron, and steel.—R. A. R.

**Equipment, from the French Industry for the New Iron and Steel Making Centres in South America.** (*Echo Mines*, 1952, May, 316). The recent development of iron and steel making in Columbia and Peru is outlined.—T. E. D.

**The French Fine and Special Steel Industry.** (*Usine Nouvelle*, 1952, **9,** Dec. 18, 13). The organization of the industry is briefly surveyed, and production trends are tabulated, giving details of types of furnaces used.—T. E. D.

**Iron and Steel Production 1851–1951, and the Coke Industry.** W. Mathesius. (*Blast Furn. Steel Plant*, 1952, **40,** Nov., 1305–1310, 1346). The development of iron and steel making processes in America over the last 100 years is surveyed and a number of important discoveries which have affected the industry are discussed. The development of biproduct coke-oven plants is also surveyed.—B. G. B.

**Coke and By-Products in 1951.** (*Iron Steel Eng.*, 1952, **29,** Nov., 116–122). This paper gives data, submitted by coke producers to the U.S. Bureau of Mines, which show that production in 1951 was the highest ever recorded. Production tonnages and trends are given together with the numbers and capacity of ovens, coal tonnages, coke produced and sold or used by producers, stock figures, and values of by-products.

**Yugoslav Iron and Steel Industry: Present Position and Future Development.** J. E. Holgate. (*Iron Coal Trades Rev.*, 1952, **165,** Dec. 26, 1409–1414). The author has recently visited the principal Yugoslav iron and steel plants and ore mines, and presents a factual account of the present situation of the industry, with special reference to the main expansion projects.—G. F.

**Iron and Steel Industry: Post-War Progress in Productive Efficiency.** G. H. Latham. (*Newport and District Met. Soc.: Iron Coal Trades Rev.*, 1952, **165,** Oct. 24, 925–926). The author considers the growth in output capacity and productive efficiency of the iron and steel industry, and stresses the need to keep abreast of technical developments and to link expansion in the steel industry with the trend of export and import markets.—G. F.

**Steelmaking in Latin America.** (*Steel*, 1952, **131,** Nov. 24, 79–81). The steel consumption and production, and iron ore and coal reserves of the Latin American countries are set out, and future trends considered.—D. L. C. P.

**A Survey of the Iron and Steel Industries in Latin America. Pt. I—Mexico, Cuba, Venezuela, Colombia, Peru. Part II—Chile.** A. Groothoff. (*Metalen*, 1952, **7,** Oct. 15, 335–338; Oct. 31, 354–356). [In Dutch]. An account is given of the raw materials for iron and steel manufacture which are available in the above countries.—R. A. R.

**Export of Iron Ore.** G. De Paiva. (*Engenharia, Mineração e Met.*, 1952, **17,** June, 133–139). [In Portuguese]. The author surveys the history of the development of mining interests in Brazil and states the Brazilian attitude towards the export of iron ore. Possible solutions to the economic, transportation, and geographical problems of shipping out the ore from Minas Gerais are dealt with and these ores are described.—R. S.

**Rails from Volta Redonda for the Re-equipment of the Brazilian Railways.** (*Engenharia, Mineração e Met.*, 1952, **17,** June, 141–144). [In Portuguese]. Since the Volta Redonda Works began rolling rails in May, 1947, they have produced a quarter of a million tons to the end of 1951. Relationships between this production and the organization of the national economy and requirements are considered.—R. S.

**Brazilian Blast-Furnaces Are Not the Main Cause of Forest Devastation.** J. B. De Araujo. (*Engenharia, Mineração e Met.*, 1952, **17,** June, 145–148). [In Portuguese]. Statistics of wood consumption for railways, metallurgical charcoal, and domestic purposes are given. Even in the metallurgical zone of Minas Gerais, domestic consumption of wood is greater than that for various industrial uses and for charcoal. Nearly all iron and steel undertakings realize the necessity for re-afforestation near the plants to guarantee future fuel supplies and to counterbalance the rise in freight charges.—R. S.

**Economic Combination of Enterprises of the Coal, Iron, Chemical and Power-Generating Industries.** W. Kleingrothaus. (*Stahl u. Eisen*, 1952, **72,** Nov. 6, 1449–1452). The possibilities of an economic and technical combination within the basic industries of coal, iron, and chemicals, are indicated.—J. P.

## MISCELLANEOUS

**The New Laboratories of IRSID at Saint-Germain-en-Laye.** R. A. Coulon. (*Ossature Métallique*, 1952, **17,** Dec., 592–594). The new laboratories of IRSID recently completed near Paris are described.—P. F.

**French Metallurgical Research: Inauguration of IRSID Laboratories.** T. Bishop. (*Iron Coal Trades Review.*, 1952, **165,** Nov. 7, 1013–1019). A description is given of the newly inaugurated research laboratories and equipment of the Institut de Recherches de la Sidérurgie Française at St. Germain-en-Laye.—G. F.

**The New Laboratories of l'Institut de Recherches de la Sidérurgie Française at Saint Germaine en Laye.** (*Génie Civil*, 1953, **130,** Mar. 1, 81–86); *Echo Mines*, 1953, Jan., 29–32). **Iron and Steel Research Institute.** (*Aciers Fins Spec. Franç.*, 1952, Dec., 8–11). A description of IRSID (Institut de Recherches de la Sidérurgie) is given. The research work is distributed over three departments, metallographic, physics, and analytical. In addition, a high temperature physical chemistry department studies such matters as slag viscosity and surface tension. The staff has 333 members including 77 engineers and technicians.—E. C. S.

**Metallurgical Research, an Important Concern of Metallurgists.** W. Oelsen. (*Stahl u. Eisen*, 1953, **73,** Jan. 1, 1–5). The importance of fundamental and applied research and their connection with practical procedures are discussed. The methods and techniques of research are briefly indicated.—J. P.

**Present Position of the Application of Job Evaluation in the Plants of the Iron and Steel Industry.** H. Euler. (*Stahl u. Eisen*, 1952, **72,** Dec. 18, 1671). The replies to a questionnaire, concerning the extent to which job evaluation is being

practised, are summarized. The advantages of the system are given.—J. P.

**Contributions to Rationalization by Means of Employee's Suggestion Schemes.** K. Theis. (*Stahl u. Eisen*, 1953, **73,** Jan. 1, 35–41). An employee's suggestion scheme, as practised in U.S.A., can be a powerful factor in increasing output. A large number of suggestions, put into effect in integrated steelworks, over a period of years, are described and illustrated.—J. P.

**An Experiment in Education.** (*Sheet Metal Ind.*, 1952, **29,** Nov., 988–990). This is a short review of the educational activities of the Worshipful Company of Tinplate Workers.

**The Principles of Technical Control in Metallurgical Manufacture.** A. R. E. Singer. (*J. Inst. Met.*, 1953, **81,** Mar., 329–340). The effects of economic and technical factors on the quality of manufactured products are examined, and the characteristics of controlled processes are analysed in terms of basic principles. Some aspects of statistical control of plant are considered.—R. A. R.

**Maintenance and Materials.** F. E. Probyn. (*Proc. Ebbw Vale Met. Soc.*, 1952, **2,** 1–16). This is an account of the maintenance carried out at the steel plant of Richard Thomas and Baldwins Ltd., Ebbw Vale, and the materials used. Alloy steels of several types are discussed with reference to their uses. Changes in technique employed for achieving the desired results are also mentioned, amongst which are thermit welding, plating and metal spraying.—J. C. B.

**Radio Communication for Steelworks Shunting Locomotives.** (*Railway Gaz.*, 1953, **98,** Jan. 16, 73–74). A short account is given of G.E.C. radio communication equipment for use between control centres and locomotives at the Abbey Works, Steel Co. of Wales Ltd. The selective calling system used is applicable to a fleet of up to 70 units.—T. E. D.

**Oxygen—Its Preparation and Use in Industry.** H. Beduneau. (*Rev. Produits Chim.*, 1952, **55,** Nov., 405–410). The essential features of several different types of plant for producing oxygen on a commercial scale are described. The economical operation of the plant depends on a number of factors, the most important of these being the rated output of the plant and the purity of the oxygen required.—B. G. B.

**The Production and Use of Oxygen on a Large Scale.** B. F. Dodge. (*Chim. et Ind.*, 1952, **68,** July, 44–52). A comprehensive survey of the historical development of oxygen production is presented. Present applications of oxygen on a large scale include its use in gas producers, for natural gas combustion to produce rich synthesis gas, for the enrichment of air for blast-furnaces, in open-hearth steel production, and in converters. Numerous uses in the chemical industry are also quoted. The production of oxygen is explained, and some details of plant capacity and power consumption related to oxygen purity are discussed.—T. E. D.

**Industrial Gases.** J. R. Park. (*Soc. Chem. Ind., Reports on the Progress of Applied Chemistry*, 1951, **36,** 389–403). The article surveys the production and use of products of air separation processes, acetylene, liquified petroleum gases, carbon dioxide, nitrous oxide, and hydrogen. Oxygen is considered in some detail. Methods of large scale production are outlined and the uses of 'tonnage' oxygen in industry are given. (70 references).—T. E. D.

**Application of Science to Industry.** Lord Halsbury. (*Times Rev. Ind.*, 1952, **6,** Dec., 10–11). The place of the National Research Development Corporation in bridging the gap between invention and production is discussed. Its scope covers the demonstration of an invention, pilot plant or prototype, and initial production.—T. E. D.

**The Intuitive Basis of Modern Thermodynamics.** W. Mund. (*Chim. et Ind.*, 1952, **67,** May, 741–748). It is essential that the basic ideas of modern thermodynamics should be understood if they are to be used. The concepts employed and their exact significance are discussed with particular reference to enthalpy and entropy.—T. E. D.

**Essential Requirements of Efficient Industrial Lighting.** P. H. Billington. (*Mech. World*, 1952, **132,** Sept., 112–114). The vital elements in the provision of good and adequate lighting, suitably arranged in workplaces, are described.—D. H.

**Pollution Problems of the Iron and Steel Industry.** R. J. Sarjant. (*Iron Steel*, 1952, **25,** Nov., 501–502; *Iron Coal Trades Rev.*, 1952, **165,** Sept. 26, 711–712). The author discusses pollution problems arising from the production of smoke, fumes, and dust in the course of the processes operated in the iron and steel industry. Various types of dust removing plant are briefly described, and the present position is summarized.—G. F.

**The Separation of Airborne Dust and Particles.** C. N. Davies. (*Inst. Mech. Eng. Advance Copy*, July 31, 1952). The author deals with the physical principles of different kinds of separator, so that their design can be understood and appropriately applied. Emphasis is entirely on fundamental considerations which lead to formulæ of value to designers. New theories of the conical elutriator, the cyclone, and of fibrous filtration are put forward. (33 references).—P. M. C.

**The Science and Practice of Dust Collection as Applied to Industry.** G. F. H. Peacock. (*J. Trans. Jun. Inst. Eng.*, 1952, **62,** Sept. 422–431). The author gives reasons why dust collection is necessary in industry and discusses the selection of fans based on the type of atmosphere in the plant and the final requirements. Methods of separation and filtration of the dust particles are considered.—J. C. B.

**Some Experiences with Air Pollution Abatement in the Steel Industry.** C. A. Bishop. (*Blast Furn. Steel Plant*, 1952, **40,** Dec., 1448–1453; *Iron Steel Eng.*, 1952, **25,** Dec., 122–126). After discussing the dust control in open-hearth operation the author describes the difficulties involved in the removal of fume from blast-furnaces producing ferromanganese. A pilot plant was constructed to deal with this problem and details of its successful operation are given.—B. G. B.

**Atmospheric Pollution.** L. C. McCabe. (*Indust. Eng. Chem.*, 1952, **44,** Nov., 123A–125A). Details are given of the "DEP" (De Permentier) curtain-type dust-collector, which embodies equally-spaced curved **U**-profile filter elements.

**Heating and Ventilating a Heavy Engineering Works.** (*Indust. Heating Eng.*, 1953, **15,** Jan., 11–15). Details of space heating and ventilating plant installed at the General Electric Company's new turbo-alternator works at Witton are given.—T. E. D.

**How Weirton Steel Guards Against Fire.** E. T. Davis. (*Iron Age*, 1952, **170,** Sept. 25, 113–116). Extensive use, at this plant, is made of built-in fire-fighting systems and this, together with portable extinguishers, keeps fire damage and stoppages at a minimum. Portable equipment consists mainly of the $CO_2$-emitting type. Special classes are held to train personnel in the use of various types of extinguisher.—A. M. F.

**Accident Control in Rolling Mills.** C. Kendall. (*Iron Steel Eng.*, 1952, **29,** Nov., 98–99). Accident prevention activities in the departments of The Bethlehem Steel Co. are described.

**Accident Prevention in American Iron and Steel Works.** A. Elson and P. Wright. (*Iron Coal Trades Rev.*, 1952, **165,** Nov. 14, 1059–1062). The authors have made a detailed study of accident prevention methods adopted in American iron and steel works, and present their personal recommendations for decreasing the accident rate in the British iron and steel industry.—G. F.

# BOOK NOTICES

BRITISH WELDING RESEARCH ASSOCIATION. "*The Welding of Austenitic Corrosion- and Heat-Resisting Steels.*" With a Foreword by Sir Ben Lockspeiser, Secretary of the Department of Scientific and Industrial Research. 8vo, pp. xiv + 207. Illustrated. London, 1953: The Association. (Price 27*s.* 6*d.*)

This book is the result of several years' intensive work on the part of a committee of specialists, representing both the steel manufacturers and the user, brought together by the British Welding Research Association. Its scope is specifically confined to stainless steels of the 18/8 variety, and this has enabled the subject to be treated in a considerably more exhaustive manner than is done in previously available literature. Its importance in various industries is brought out in a foreword by Sir Ben Lockspeiser.

The first three chapters deal generally with welding methods, metallurgy, and the control of distortion, and the next eight with each of the main welding processes as applied relatively recently, such as submerged arc welding, resistance welding, and, in particular, Argonarc welding.

A chapter devoted entirely to cutting methods for stainless steels focuses attention on oxidation and fluxing methods

of cutting, as opposed to mechanical methods, these latter being slow and costly, owing to the tough and work-hardening nature of 18/8 steels. The iron powder injection method, and the flux injection method would seem to be the most promising methods from the economical aspect.

The problem of carbide precipitation and the resulting effect known as " weld decay " are adequately dealt with in a chapter on heat-treatment after welding. Further chapters cover surface finishing after welding, weld inspection, tests for welders, welding 18/8 steels to other metals, the welding of clad steels, and the welding of special heat-resisting steels.

An appendix contains useful data on proprietary makes of 18/8 steels and chromium–nickel heat-resisting steels. Standard specifications for chromium–nickel corrosion- and heat-resisting steels are also given. Finally a selected bibliography and index complete a well considered and well prepared book.

Although the book is essentially most accurate in its details and fundamental background, it is not written on a high level which would preclude its use by the man in the shop. It will, in fact, be found invaluable to welding engineers, foremen, and works managers who come face to face with the actual practical details of welding, because it is heavily loaded with tables of suggested settings for welding machines, facts, and data on techniques, and is profusely illustrated with first-class photographs and diagrams which in themselves are self explanatory.

A. J. HIPPERSON

CHALMERS, BRUCE (Editor). " *Progress in Metal Physics.*" Vol. 4. La. 8vo, pp. viii + 403. Illustrated. London, 1953 : Pergamon Press, Ltd. (Price 60*s.*)

The now familar pattern of the " *Progress in Metal Physics* " series has been preserved in the latest issue. The book contains seven review articles, of which four represent expositions of subjects which could be classified under the broad heading of the " Physics of Solids," and three which fall into the domain of physical metallurgy and physical chemistry. Amongst the first four belongs a lucid exposition of recent developments in the Theory of "Dislocations," a contribution which, taken with its predecessor in Vol. I., can be regarded as an excellent monograph on a subject of profound importance to the future developments of metallurgical science.

" Diffusion in Metals " is discussed by A. Le Claire in the same competent way as was done earlier by the same author in Vol. I. When it is considered that self-diffusion and the diffusion of metal in metal are involved in practically every alloying and heat-treatment process in metallurgy, the lack of data appears to be in urgent need of remedy. Small amounts of impurities, such as carbon in iron or lead in silver, have a very considerable influence on self-diffusion coefficients and important effects of this type cannot be effectively interpreted without much more experimental work. In the case of " Nucleation," J. H. Hollomon and D. Turnbull voice a similar view, and they conclude their contribution with the emphasis on the need for data to test current theories relating to the nucleation of precipitates in solids.

A. S. Novick's review of " Internal Friction in Metals " deserves to be read carefully, for the measurement of internal friction can often be a simple method for elucidating the nature of ordering in solid solutions, for non-destructive measurements of grain sizes at high temperatures, and for dealing with problems associated with annealing, cold working, magnetism, etc.

In " Gases in Metals," C. R. Cupp deals with gas-metal equilibria, diffusion and solution, internal oxidation, and effects of dissolved gases on the physical and mechanical properties of metals. The perennial problem of hair-line cracks in steels also receives due attention.

A stimulating review of the " Theory of Sintering " is given by G. A. Geach, and a thorough exposition of " The Mechanism of Oxidation of Metals and Alloys at High Temperatures " by K. Hauffe.

Some of the subjects in the book will no doubt appeal primarily to the specialist, though the variety of approach and the diversity of thought among workers in the field of metals, reflected in the contributions, should provide inspiration for the metallurgist occupied with immediate practical problems. If the blending of the abstract and the concrete achieved in this book by the editor were consistently translated into all forms of research, many problems still with us to-day would no longer be awaiting solution.—P. FELTHAM

" *Gmelins Handbuch der anorganischen Chemie.*" 8. Auflage, System-Nummer 9 : " *Schwefel.*" Teil A, Lieferung 2 : " *Vorkommen. Technologie des Schwefels und seiner Verbindungen. Kolloider Schwefel. Physiologische Schädigung.*" 8vo, pp. 61–510 + index. Illustrated. Weinheim/Bergstrasse, 1953 : Verlag Chemie G.m.b.H. (Price DM 147.–)

This latest volume of ' Gmelin ' deals with the technology of sulphur and some of its compounds, and appears to do so with a completeness that we have come to expect from the authors of this collaborative work. The literature has been reviewed up to the end of 1949, so that this must be regarded as a source and reference book of extreme value, containing full information and literature references concerning any of the subjects in the expensive index.

The first chapter discusses the occurrence of sulphur and its compounds in stars and meteorites, in the earth's soil, waters and atmosphere, and in the organisms living in or on the earth. Two sections are of topical interest ; one deals with the rôle of microbiological organisms in the oxidation and reduction of sulphur compounds and their geochemical importance, and the other gives a topographical review of the major deposits of sulphur minerals over the five continents.

In the second and main chapter a survey of the production and consumption of sulphur and sulphur minerals and the uses to which they are put is followed by sections on the preparation and beneficiation of raw materials and on the winning of elemental sulphur from deposits of the native element, sulphide ores, decomposition of sulphur-bearing gases, and coal ; this latter section is very pertinent to today's problems for it describes many processes by which sulphur, now allowed to go to waste, may be recovered to supplement the world's dwindling supplies of this vital material. The next, short, section describes the production and storage of hydrogen sulphide, and the following one the production, purification, concentration and storage of sulphur dioxide. The section concerned with the production of sulphur trioxide and sulphuric acid is the largest and most detailed in the book. The contact process and the lead chamber process (which in some circumstances is still the most economic way to produce sulphuric acid) receive very full treatment, and other methods, including autoxidation, are not overlooked. The concentration of sulphuric acid by various methods, the purification of sulphuric acid, constructional materials for sulphuric acid plants, operational hazards and precautions, operating costs, and the production of chlorsulphonic acid are all dealt with. A noteworthy feature of this chapter is the insertion of very extensive lists of patents covering the various processes and operations.

The third chapter is concerned with the preparation, composition, uses and properties of colloidal sulphur, mainly as hydrosols, and the final chapter sums up the physiological actions of sulphur, hydrogen sulphide, sulphur dioxide, sulphuric acid, sulphur chlorine compounds, and hydrogen polysulphides.

This volume is one that every chemist and chemical technologist could frequently consult with profit ; it is likely however, that owing to the high price it will not be as readily available as it should be.—J. PEARSON

INSTITUTE OF WELDING. " *Notch Bar Testing and its Relation to Welded Construction.*" Symposium organised by the Institute of Welding in association with the Joint Committee on Materials and their Testing, 5 December, 1951. La. 4to, pp. 79. Illustrated. London, 1953 : The Institute. (Price 25*s.*)

In recent years, attention has been sharply focused on many catastrophic failures of welded steel constructions, notably bridges in Europe, American ships, and oil refinery plant in Britain. The appearance of this publication is timely, and it points the way to possible causes of failure, and methods of preventing future failures ; it contains the five papers presented at a symposium organized in 1951, together with the verbal discussion and correspondence which arose.

Brittle fracture, it is stated, is a function of notch ductility, which cannot be regarded as a simple property of steel comparable with tensile strength ; it is a simple term which really expresses the relative capacity of steel for plastic deformation under adverse conditions of stress concentration, temperature, and rate of loading. In the simple notch bar impact test, part of the fracture produced is shear, and part cleavage. Under conditions encouraging brittle fracture, the percentage of cleavage fracture is high. Attention of the steelmaker has been devoted to the development of laboratory tests which correctly guide the engineer in the choice of his steel. W. Barr's paper gives valuable information on these factors, and is backed by a paper by G. M. Boyd, who analyses the usefulness of each type of notch test ; however, he skips over the theory of the Schnadt test, a very useful and informative practical test.

Professor Ing. W. Soete's paper deals with the state of stress and brittle fracture, and it is supported by a vast collection of practical results. Constance F. Tipper's paper attempts to relate notch-bar tests to service performance, and finally, J. H. van der Veen describes a special testing method for brittle fracture of mild steel plates.

The ensuing discussions, which are reported, go a long way towards tying the five main papers together, and the publication as a whole marks a valuable step forward towards the full understanding of the problems of brittle fracture.—A. H. Hipperson

# NEW PUBLICATIONS

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